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ABSTRACT

Designed for eleventh-grade students, this activity book contains nineteen electrical experiments. Experiments focus on topics such as commercial application of electromagnets, electromagnetic instruments, and commercial generators. Each experiment follows a typical format that includes the following parts: purpose, material used, procedure, questions, and references. The experiments are preceded by a series of information sheets and job sheets that provide the student with information on topics such as electrical wiring specifications, testing fuses, interior lighting design, home lighting, and the incandescent lamp. (LRA)

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CONNECTICUT STATE DEPARTMENT OF EDUCATION
DIVISION OF VOCATIONAL EDUCATION
HARTFORD

ELECTRICAL EXPERIMENTS

YY-214-1

GRADE 11

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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Estimating Specifications

ELECTRICAL WIRING SPECIFICATIONS

General Conditions

In most cases involving new construction, specification papers are prepared by the architect and should be carefully studied by the electrical contractor. In old or existing residences or other buildings specifications sheets or plans are rarely available, and a knowledge of various materials, rules, methods and labor costs is essential. Some things to bear in mind are the types of wiring to be used such as armored cable, non metallic cable, steel tubing, conduit, or open wiring. In residential wiring jobs it must be determined if an outdoor or indoor meter is to be used and whether the circuits are to be fed from a meter board in the basement or from load centers or multibreakers panels in the upper floors. If a contractor is not familiar with the requirements of the local power company as to service and metering he should contact the meter department or company inspector in regard to this phase of the work. Before starting any electrical job it is necessary in most cities and towns to take out a permit to do the work for which a small charge is made. Upon completion of the rough wiring an inspection has to be made. This is usually accomplished by filling out an application form for inspection and filing it with the office of the local electrical inspector. A second inspection is made upon completion of the job.

Wiring Layout

It should be understood that all wiring construction has to be done in accordance with the rules and regulations of the National Electrical Code and local wiring codes. The service wiring must satisfy the rules of the local power company. Wiring systems for lighting are generally figured on the watts per square foot basis.

Article 220 of the N.E.C. specifies the wattage for general lighting loads by occupancies. The code further states a requirement of one lighting circuit for every 500 square feet of floor area, (this does not include open porches, garages in connection with dwellings, nor unfinished spaces and unused spaces in dwellings unless adaptable for future use,) for dwelling occupancies.

Lighting circuits are usually wired with #14 wire, and small appliance circuits in the home with #12. It should be understood that any reference to wire sizes is in copper.

In commercial buildings the number of receptacle outlets is dictated by an assessed load for each receptacle of 180 volt-amperes. (Sec. 220-2(c)). This would limit a 2-wire, 15 ampere, 115 volt circuit to a maximum of 9 connected receptacle outlets. In dwelling-type occupancies, general purpose receptacle outlets are considered to be part of the lighting load, and no additional load has to be added for the receptacle outlets.

In addition to the lighting circuits protected with 15 ampere fuses or circuit breakers, two small appliance 20 ampere circuits in the kitchen, pantry, family room, dining room and breakfast room for dwellings must be provided. Such circuits are for receptacles only and shall not extend into the living room, bedroom, etc. It should be understood that, as most code rules, this is a minimum requirement and more small appliance circuits can, and sometimes should be used. Also, these circuits (at least two) must pass through the kitchen. A further suggestion would be to install the refrigerator on a separate 20 ampere circuit.

A separate 20 ampere circuit is required for laundry receptacles (Art. 220-3(c)) and no other outlets are permitted. (Laundry circuits may not supply receptacles more than 6 feet from laundry, or not intended for laundry).

Separate circuits should be provided for ranges, water heaters, motorized appliances, air conditioning equipment, pumps, etc. when these are part of the job. These separate circuits should be installed in strict compliance with Article 220 of the N.E.C.

Methods of Supply

Two common methods are in use and are as follows:

1. Have all branch circuit fuses or breakers mounted on the meter board at the point of entrance, usually in the basement.

2. Have all branch circuit fuses or breakers mounted in panels located on the main floor or all floors with feeders running from the panels back to the main switch or to the load side of the meter.

Service Equipment Sequence

Service equipment sequence simply means the order in which the service equipment is placed. The principal parts of a service in this respect are the switch fuse and meter. The possible sequences are:

1. Switch - meter - fuse
2. Switch - fuse - meter
3. Meter - switch - fuse

If outdoor metering is used No. 3 is the proper sequence to use. With an inside meter No. 1 is the common method. Following are some common distribution and feeder systems employed in interior wiring.

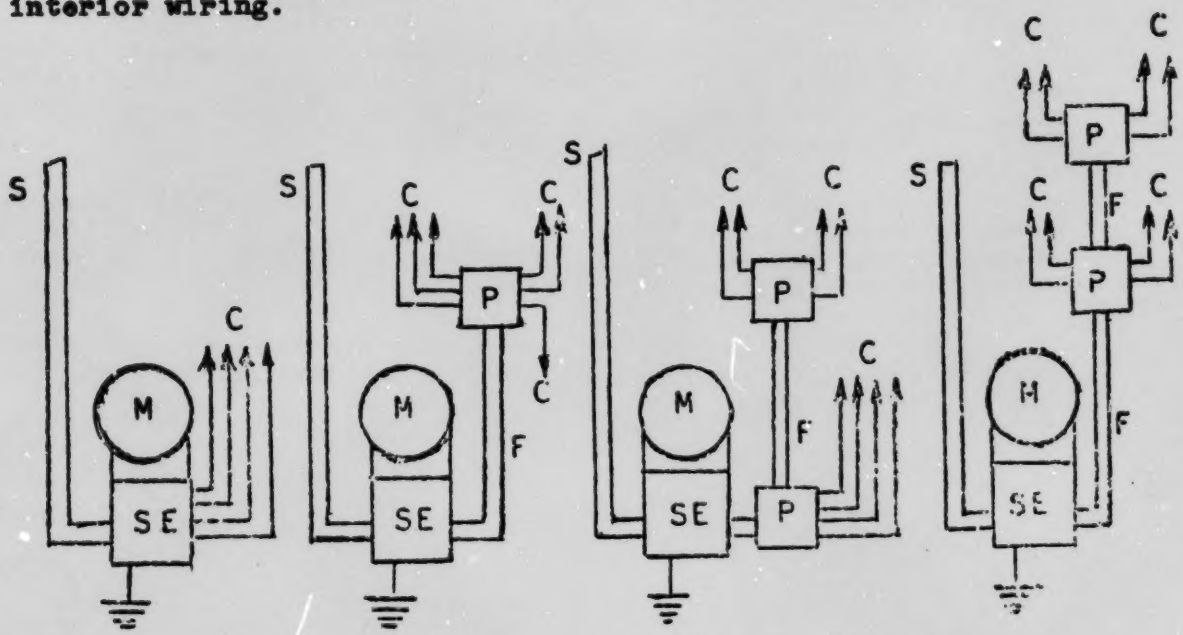
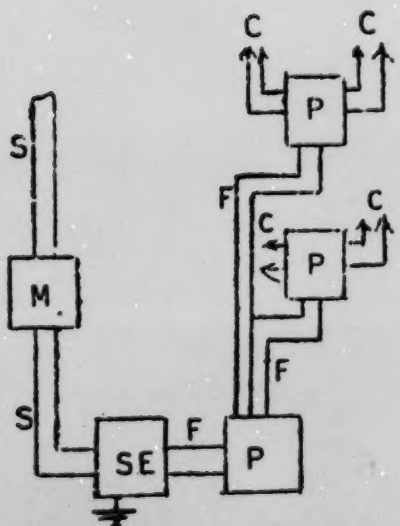


Fig. 1 Types of Service and feeder layout.

S	Service wire	P	Distribution Panel
M	Motor	F	Feeder
SE	Service Equipment	C	Branch Circuits



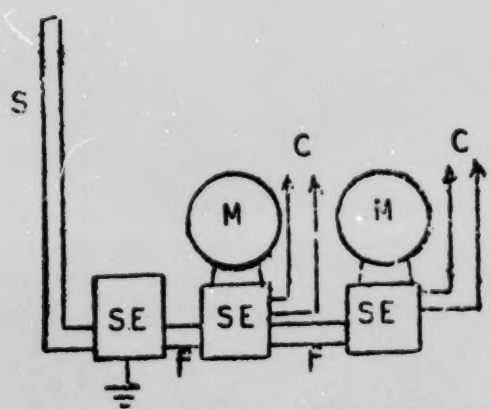


Fig. 2 SERVICE AND FEEDER LAYOUT

Branch Circuit Methods

1. Lighting branch circuit only.
2. Lighting and convenience outlets.
3. Convenience outlets only.
4. Motor branch circuits.

In lighting branch circuits there are two common methods employed of connecting the outlets. One is known as outlet to outlet with switch loops, the other is simply outlet to outlet. They are illustrated in Fig. 3 and Fig. 4.

Motor branch circuits ordinarily consist of (a) the branch circuit fuses or protective device, (b) the line wires, (c) the disconnecting switch, (d) the overload relay and (e) the control switch or controller.

The controller may be a manually operated switch, a magnetic switch with push button control station, thermostat, pressure switch or other form of controller.

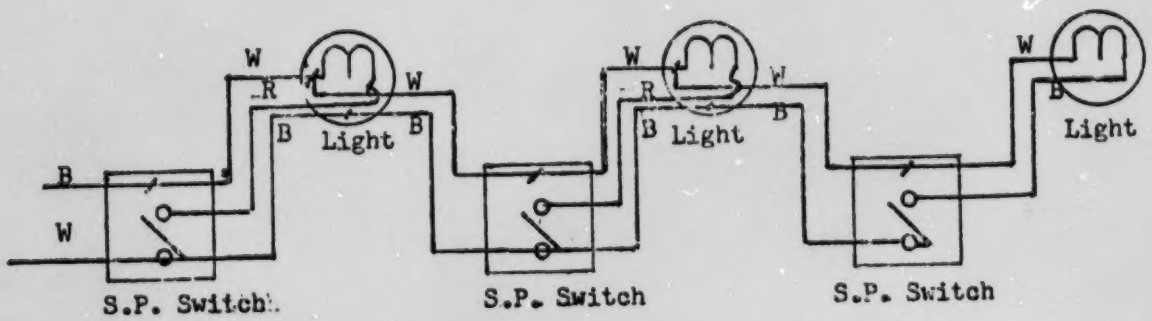


Fig. 3

Outlet to outlet method of wiring using alternate runs of 2 wire and 3 wire cable.

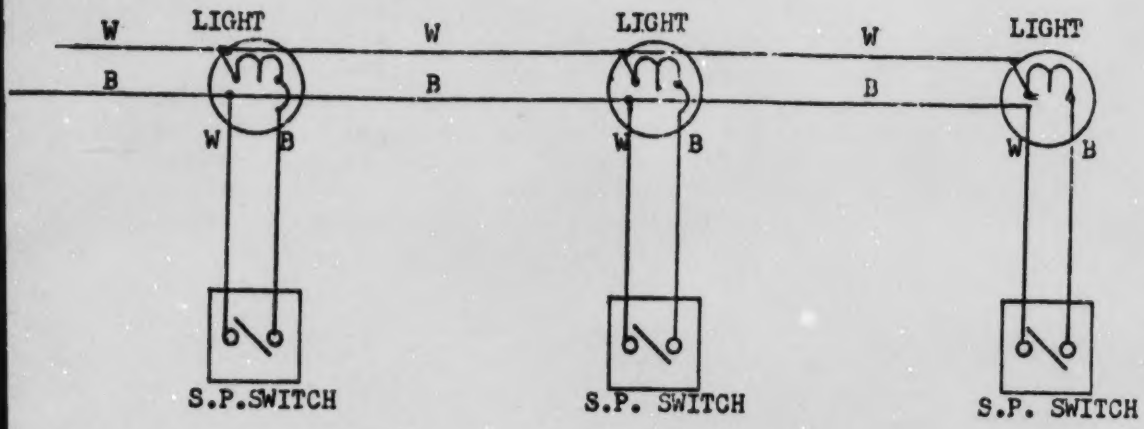


Fig. 4

Outlet to outlet scheme of wiring with so called switch loops, using all 2 wire cable.

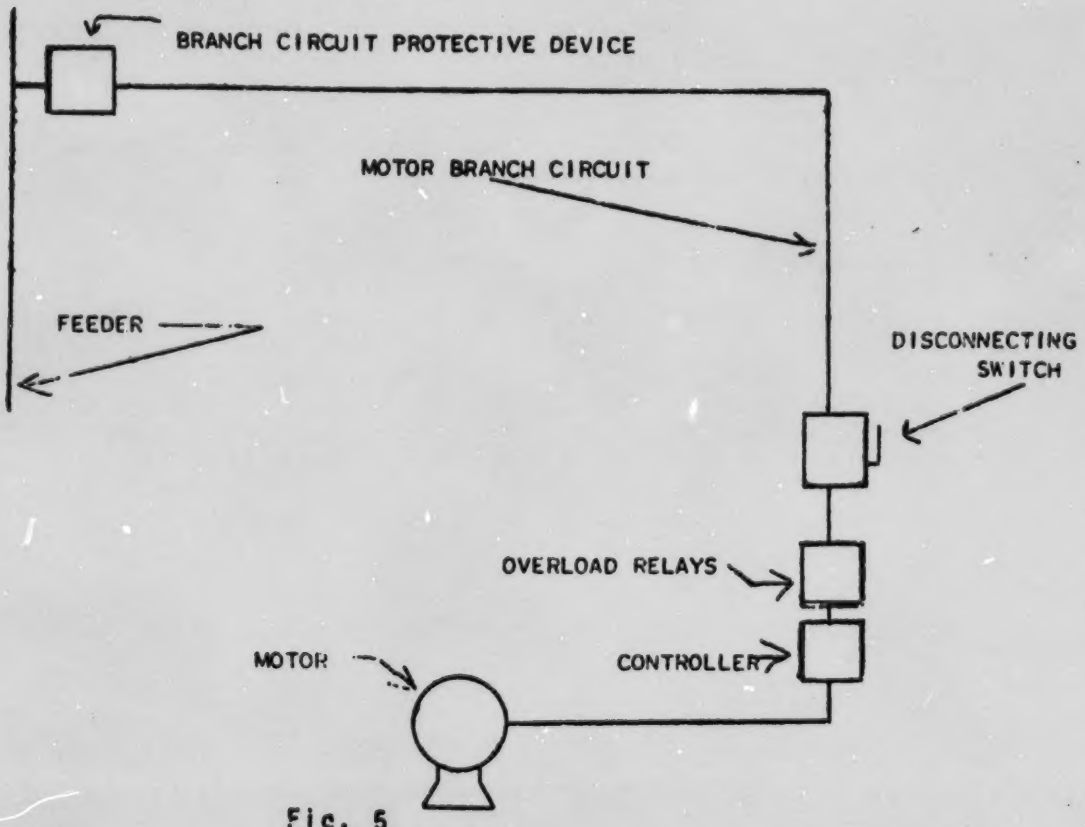


Fig. 5

General character of Motor Branch Circuits. (Single line diagram). The conductor size must be such that it will have a carrying capacity equal to one and one quarter times the full load current rating of the motor as shown on the name plate. The branch circuit protective device consists of fuses or breakers rated at three times the motor rating in Amperes. The disconnect switch and the controller must be rated in horsepower equal to that of the motor. The overload relay heaters have a rating equal to one and one quarter times the full load rating of the motor.

Outlet Requirements

1. Provide at least one convenience outlet for each 12 feet of linear wall space around the room or major fraction thereof. Example: A room 25 feet x 14 feet should have at least four convenience outlets since the linear perimeter of the room is 78 feet. This is a minimum requirement and should in most cases be increased.

2. Provide switches for all light where practical. Pull socket lights should be avoided in favor of wall switches in most cases.

3. Provide three and four way switches in rooms having more than one entrance and exit door and in all stairways.

Plans and Blueprints

Plans are considered a part of the specification of a job. Blueprints of the plan view of the floors in a building show the various outlets and switches and the control of the lights by the switches is indicated by dotted lines drawn between each switch and the outlets they control. In order to read an architectural drawing of a wiring system it is necessary to know the various symbols used and what they stand for. See Fig. 6.

References

Whitehorne "Electrical Wiring Specifications" - McGraw-Hill

"National Electrical Code"

American Electrician's Handbook

Industrial Electricity, Nadon and Gelmine

GRAPHICAL ELECTRICAL SYMBOLS FOR ARCHITECTURAL PLANS

GENERAL OUTLETS

Ceiling Wall

- Outlet
- Blanked Outlet
- Drop Cord
- Electric Outlet; for use only when circle used alone might be confused with columns, plumbing symbols, etc
- Fan Outlet
- Junction Box
- Lamp Holder
- $(L)_{PS}$ Lamp Holder with Pull Switch
- Pull Switch
- Outlet for Vapor Discharge Lamp
- Exit Light Outlet
- Clock Outlet (Specify Voltage).

CONVENIENCE OUTLETS

- Duplex Convenience Outlet
- $\rightarrow_{1,3}$ Convenience Outlet other than Duplex 1=Single, 3=Triplex, etc
- $\rightarrow_{WP}$ Weatherproof Convenience Outlet
- $\rightarrow_{R}$ Range Outlet
- $\rightarrow_{S}$ Switch and Convenience Outlet
- Radio and Convenience Outlet
- Special Purpose Outlet (Des. in Spec.)
- Floor Outlet

SWITCH OUTLETS

- S Single Pole Switch
- S_2 Double Pole Switch
- S_3 Three Way Switch
- S_4 Four Way Switch
- S_D Automatic Door Switch
- S_E Electrolier Switch
- S_K Key Operated Switch
- S_P Switch and Pilot Lamp
- S_{CB} Circuit Breaker
- S_{WCB} Weatherproof Circuit Breaker
- S_{MC} Momentary Contact Switch
- S_{RC} Remote Control Switch
- S_{WP} Weatherproof Switch
- S_F Fused Switch
- S_{WF} Weatherproof Fused Switch

SPECIAL OUTLETS

$O_{a,b,c,etc}$
$\rightarrow_{a,b,c,etc}$
$S_{a,b,c,etc}$

Any standard symbol as given above with the addition of a lower case subscript letter may be used to designate some special variation of standard equipment of particular interest in a specific set of architectural plans.

When used they must be listed in the Key of Symbols on each drawing and if necessary further described in the specifications.

PANELS, CIRCUITS, AND MISCELLANEOUS

- Lighting Panel
- Power Panel
- Branch Circuit; Concealed in Ceiling or Wall
- Branch Circuit; Concealed in Floor
- Branch Circuit; Exposed
- Home Run to Panel Board. Indicate number of circuits by number of arrows.
  Note: Any circuit without further designation indicates a two-wire circuit. For a greater number of wires indicate as follows: -//- (3 wires) -///- (4 wires), etc.
- Feeders. Note: Use heavy lines and designate by number corresponding to listing in Feeder Schedule.
- Underfloor Duct and Junction Box. Triple System.
  Note: For double or single systems eliminate one or two lines. This symbol is equally adaptable to auxiliary system layouts.
- Generator
- Motor
- Instrument
- Power Transformer (Or draw to scale.)
- Controller
- Isolating Switch

AUXILIARY SYSTEMS

- Pushbutton
- Buzzer
- Bell
- Annunciator
- Outside Telephone
- Interconnecting Telephone
- Telephone Switchboard
- Bell-Ringing Transformer
- D Electric Door Opener
- FB Fire Alarm Bell
- F Fire Alarm Station
- City Fire Alarm Station
- FA Fire Alarm Central Station
- FS Automatic Fire Alarm Device
- W Watchman's Station
- WI Watchman's Central Station
- H Horn
- N Nurse's Signal Plug
- M Maid's Signal Plug
- R Radio Outlet
- SC Signal Central Station
- Interconnection Box
- Battery
- Auxiliary System Circuits
  Note: Any line without further designation indicates a 2-wire system. For a greater number of wires designate with numerals in manner similar to —·— 12-No. 18W-3/4"C., or designate by number corresponding to listing in Schedule.
- $\square_{a,b,c}$ Special Auxiliary Outlets.
  Subscript letters refer to notes on plans or detailed description in specifications.

Questions

1. Who are specifications designed to protect?

2. Are local power company requirements standard or do they vary from company to company?

3. Why are permits required for electrical construction in most cases?

4. How many circuits ordinarily should be planned for in a residence of 2,000 square feet for lighting? What other circuits should be included.

5. In an outdoor meter installation in a residence, what would probably be the metering sequence?

6. What are the elements of a motor branch circuit and what is the order of their placement?

7. How is switch control indicated on an architectural plan?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Job #1
Page 1 of 1

Estimating

Purpose: To teach student how to estimate a single family dwelling you have a single family house with the following dimensions which is to be wired.

1st floor	40 ft. x 30 ft.
2nd floor	40 ft. x 20 ft.
Basement	25 ft. x 20 ft.

Procedure:

1. Compute the General lighting load.
2. Determine the number of 15 ampere lighting circuits required.
3. Determine the size of service conductors to feed this house using a 3 wire system, if 2 utility circuits are required and a 8.5 KW range is used.
4. Calculate the size of service conduit required.
5. Determine the size ground wire needed in this house.
6. Give code rules for each part of job.
7. Calculate size, type, number of circuits and fuse capacity of Main Panel.

References: National Electrical Code 1978, Example No. 1 - Single Family Dwelling

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Job #2
Page 1 of 1

Estimating

Purpose: To teach student how to estimate a multi family dwelling a customer wants a building wired which consists of 6 apartments, each of which has a floor area of 400 square feet. Each apartment has an electric range rated at 8.5 KW.

Procedure:

1. Figure the amount of current to be used in each apartment after applying demand factors.
2. Figure amount of current needed for the whole house after applying the demand factor.
3. Determine size wires for feed to Main Panel, also size and rating of this panel.
4. Find size of conduit required for Main feeds.
5. Calculate size of ground wire to be used.
6. Determine size wire and type of Panel used to feed each apartment.

References: National Electrical Code 1978, Example #4 - Multi-Family Dwelling.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Job #3
Page 1 of 1

Estimating

Purpose: To give the student an understanding of the methods used in estimating an electrical wiring job.

Materials Used:

Blueprint of job instructor wants student to estimate, ruler, pencil and paper, code book.

Procedure:

1. Study print carefully, note scale and all electrical symbols showing equipment and locations.
2. Compute General Lighting Load.
3. Determine number of lighting circuits, whether 15 amp., or 20 amp.
4. Determine total load of entire building.
5. Find size of Main feeds, ground wire and type and rating of Main Panel.
6. Calculate and list all equipment to be used on this job.
   a. Using scale of print; lengths of run of wires and cables can be determined
   b. Using symbols, the number of switches, lights, fixtures, etc. can be listed
   c. It is suggested that each circuit be drawn separately (in different colored pencil) and the totals added to find the required amount of equipment to be used
   d. When determining total amounts of wire and cable allow 10% more for obstructions and variances in construction

References: National Electrical Code 1978, Examples in back of code.

FUSES AND BREAKERS

Explanatory Notes

Each conductor which may be used as part of an electric circuit may safely carry not over a definite amount of current according to the area of the conductor. At times these conductors may be subjected to current loads in excess of their safe carrying capacities. Therefore, it becomes necessary by some means to properly protect these conductors from overheating due to overloads or short circuits. As manual protection never is practicable, these protective devices must be automatic and positive in action. This automatic overload protection of circuits is accomplished by either one of two means, fuses or circuit breakers.

A fuse is a device which operates by the melting of an alloy link within the body of the fuse. Each one of these fuses is intended for use within certain limits of current and voltage. These fuses are to the electrical circuit what a safety or relief valve is to a steam boiler or compressed-air tank. Under no circumstances should the fuse receptable be jumped with a solid conductor as this is the equivalent of tying down the safety valve which action may produce very serious and damaging results.

In the case of overloaded conductors without proper fuse or breaker protection as a potential source of fire would exist.

Fuses are of two types, plug and cartridge. Most plugs are of the one-time kind, which are discarded after they have been blown, although some of them are made with several links which are put in circuit by a movable contactor. By means of this contactor a circuit which has been interrupted may be reclosed for operation. Although not commonly used, there are renewable plug type fuses.

The cartridge fuse also is of two kinds, one-time and renewable. After it has been blown the one-time kind is discarded. A new link may be placed in the shell of the renewable kind, thereby making the assembly ready again for use.

In replacing blown links one should be careful to clean all contact surfaces and set tight all screw contacts. Failure to do so will result in more or less resistance at these contacts with possible excessive heating at the ends, burning off the link at that spot and opening the circuit under less than full load. Also one must be certain to have good and full surface contact at the ferrules and knife blades in order to avoid excessive heating and possible interruptions.

Both the plug type and the cartridge type fuses are made for either instantaneous or time-lag operation. Those for instantaneous operation interrupt the circuit soon after an overload develops while the time-lag type requires more of an interval of time to elapse before operating. Unless an overload remains for sufficient time no serious heating will develop. Hence it is not necessary in all cases of overload to interrupt the circuit at once. This is an advantage in any place where continuity of service is especially desirable. As often an overload is of only a few seconds duration this time lag feature of protective devices prevents an unnecessary interruption of service.

Fuses are rated and identified as follows:

Type	Amps	Volts	Contact	Identification
Plug	0-15	125/250	Screw Shell and Center	Hexagonal current rating on center contact
Plug	16-30	125/250	Screw Shell and Center	Round marking current rating on center contact
Cartridge	0-15	250	Ferrule	Navy Blue label
Cartridge	16-30	250	Ferrule	Green label
Cartridge	31-60	250	Ferrule	Green label
Cartridge	61 & over	250	Knife-blade	Green label
Cartridge	0-30	600	Ferrule	Red label
Cartridge	31-60	600	Ferrule	Red label
Cartridge	61 & over	600	Knife-blade	Red label

A device known as a fuse block or cutout block is used to hold these fuses in their respective circuits. As the applications of these blocks are several so there are several types of blocks for these applications. They are designed according to the number of wires which pass through them, or the number of poles. The number of fuses, and whether or not one leg is solid and the uses which are to be made of them. In general we might say that blocks are known as main-line, single-branch, and double-branch. The blocks are built with Edison base receptacles for plug fuses and ferrule or knife-blade receptacles are cartridge fuses.

Types of Fuse Blocks

(P = Plug Fuse C = Cartridge Fuse)

Type	Pole		Fuses	Solid Neutral	Branch Volts	Fuse Type
	Main	Branch				
Main Line	1-2-3	1-2-3	1-2-3	---	Up to 600	P or C
Single Branch	2	2	1	1	125	P
Single Branch	2	2	2	---	250	P or C
Single Branch	3	3	2	1	125/250	P
Single Branch	3	3	3	---	250	P or C
Double Branch	2	2	1 ea. br.	1	125	P
Double Branch	2	2	2 ea. br.	---	250	P or C
Double Branch	3	2	1 ea. br.	1	125	P
Double Branch	3	2	2 ea. br.	---	250	P or C
Double Branch	3	3	2 ea. br.	1	125/250	P or C
Double Branch	3	3	3 ea. br.	---	250	C
Double Branch	3	3	2 ea. br.	1	125/250	P

CIRCUIT BREAKERS

Single-pole Breaker

NEC 380-8 Circuit breakers used as switches shall be readily accessible and operating handle not over 6½ feet from floor or platform. (See Ex 1, 2, 3.)

NEC 380-3 Circuit breakers shall be externally operable and enclosed.

NEC 380-2 (b) Circuit breakers shall not open grounded conductor except: (1) where all conductors of circuit are disconnected simultaneously; (2) where so arranged that grounded conductors cannot be disconnected until all ungrounded conductors of circuit have been disconnected.

NEC 110-9, 230-98 Shall have interrupting capacity sufficient for available fault current.

NEC 110-10 Shall be selected and coordinated to clear without damage to electrical components of circuit.

NEC 240-81 Shall clearly indicate when open (off) or closed (on). On switchboards where mounted vertically the up position of handle shall be "on" position.

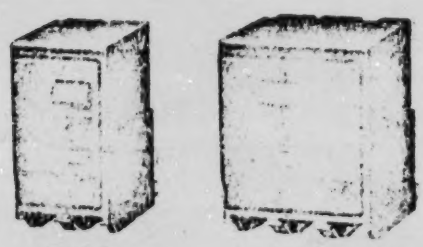
(Photo courtesy Square D Company)

NEC 240-82 Shall be designed so that trip point or time for operation will require dismantling or breaking of seal.

NEC 240-83 MARKING-(a) Shall be marked with rating and be visible after installation. Shall be visible after removal of trim or cover. (b) If 100 amps or less and 600 volts or less, rating shall be marked into handles or escutcheon areas. (c) If other than 5000 amps, rating shall be on breaker. Exception: rating not required if used for supplementary protection.

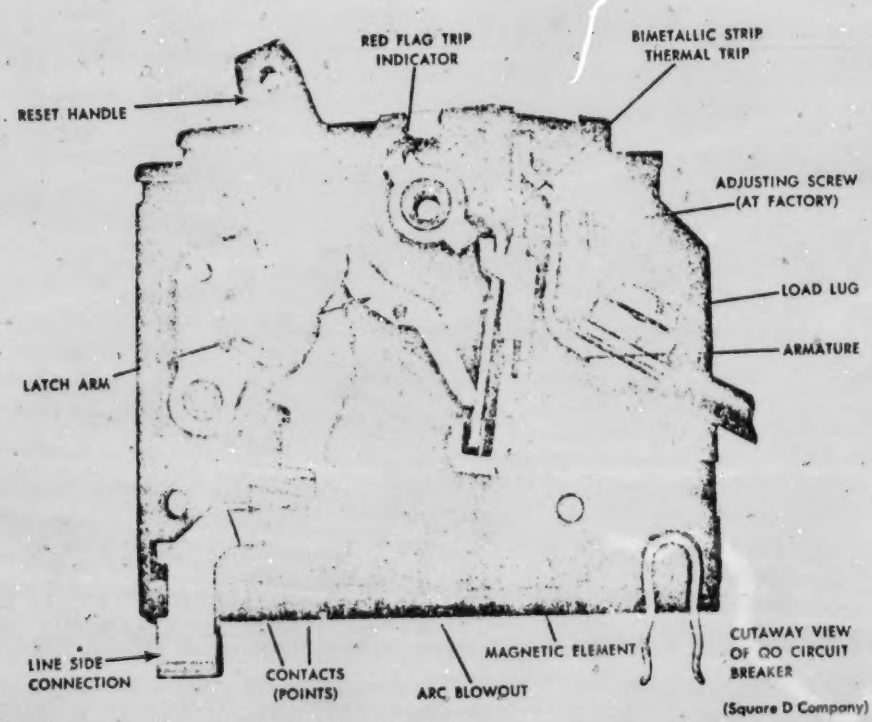
NEC 240-6 Standard ratings for inverse time circuit breakers shall be: 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, 6000 amps.

NEC 240-8 Shall not be connected in parallel, except if assembled in parallel and tested and approved for purpose.



Two-pole Breaker

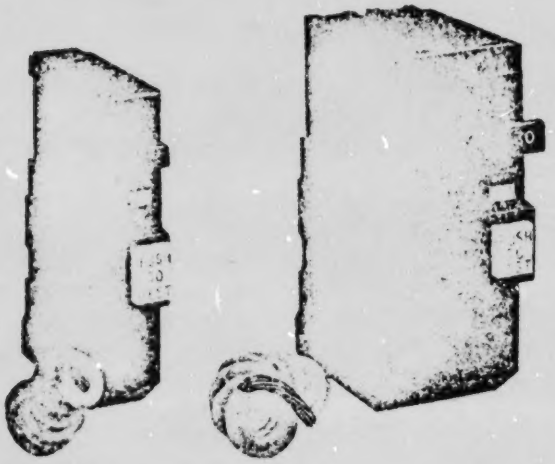
Three-pole Breaker



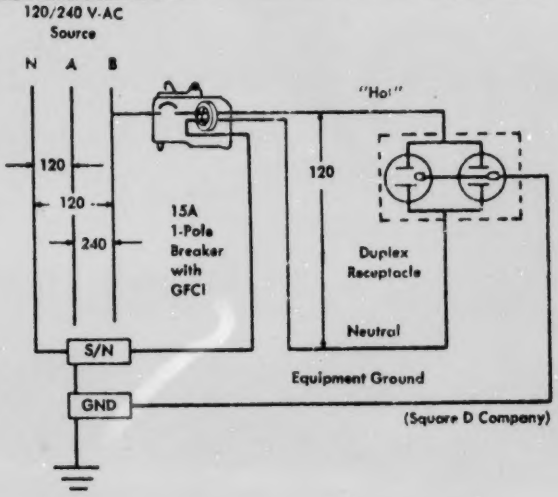
(Square D Company)

NEC ARTICLE 100—DEFINITION OF CIRCUIT BREAKER:
A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating. (See Article 100 for definition of adjustable, instantaneous trip, inverse time, nonadjustable and setting.)

GROUND FAULT INTERRUPTERS (GFCI) FOR PERSONAL PROTECTION



1-Pole Qwik-Gard 2-pole Qwik-Gard (Square D Company)



WIRING OF 1-POLE QWIK-GARD

Ground fault circuit interrupters for personal protection are required by the NEC in the following areas:

NEC 210-8 (a) Residential Occupancies: on all 120-volt, single-phase, 15- and 20-amp receptacle outlets outdoors and in bathrooms.

NEC 210-8 (b) Construction Sites: on all 120-volt, single-phase, 15- and 20-amp receptacle outlets not a part of permanent wiring, except receptacles on portable generator not over 5 kW where circuit conductors are insulated from earth and generator frame is insulated from earth and all grounded surfaces.

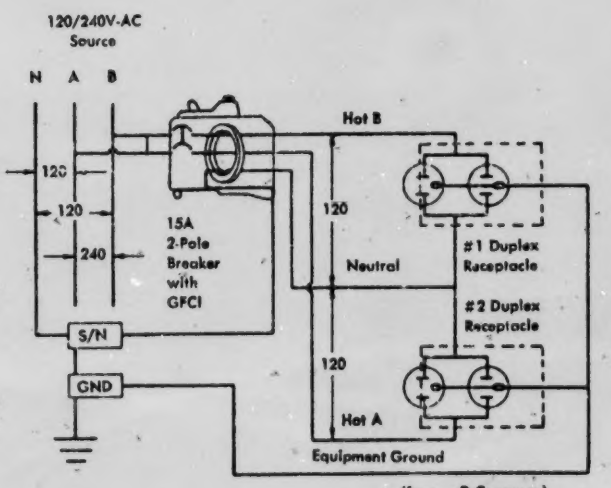
NEC 680-6 Swimming Pools—Lighting Fixtures, and Lighting Outlets: (a) Receptacles: on all receptacles located 10 and 15 feet of inside walls of pool; (b) Lighting Fixtures and Outlets: (1) located not less than 5 nor more than 16 feet from inside walls of pool, (2) existing-located not less than 5 feet from inside walls of pool, (3) light fixture or supporting part is less than 16 feet from water surface measured radially.

NEC 680-20 Underwater Lighting Fixtures: Approved underwater fixture operating at over 15 volts.

NEC 680-31 Storable Pools: all electric equipment used with storable pools requires GFCI.

NEC 680-41 (a) Fountains: all branch circuits supplying fountain equipment require GFCI except for 15 volts or less as per 680-5 (a).

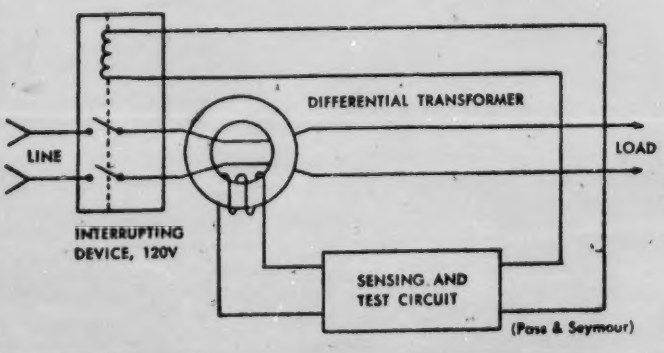
NEC 680-46 Fountains: (1) all cord and plug connected equipment including power supply cords require GFCI.



WIRING OF 2-POLE QWIK-GARD ON MULTIWIRE CIRCUITS.

NEC 680-4 (c) DEFINITION OF GROUND-FAULT CIRCUIT-INTERRUPTER (GFCI):
A device whose function is to interrupt the electric circuit to the load when a fault current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit.

GROUND FAULT CIRCUIT INTERRUPTERS RECOMMENDED BY NEC:
NEC 215-9 Feeders;
517-52 (b) Health Care Facilities;
555-3 Marinas and Boatyards;
680-5 (b) Swimming Pool Transformers



HOW IT WORKS:
Current leaking to the ground on load side of a protected circuit causes imbalance in circuit, producing a change of flux in the magnetic core of the interrupter differential current transformer. This induces voltage in transformer's secondary windings that quickly actuates solid-state circuitry causing circuit to open before any bodily harm can occur. Interrupter doesn't depend upon a third ground wire. The diagram is for Pass & Seymour's Interrupter/15.

A circuit breaker is a switching device which is designed to open a current-carrying circuit under abnormal current conditions without injury to itself. Circuit breakers of the non-adjustable type are set by the manufacturer to trip at a predetermined overload of current. Many of these breakers are designed to be tripped either by thermal means or magnetic means or by a combination of both.

The thermally-tripped breaker is operated by a mechanical mechanism upon sufficient heating by the overload current. The heating is accomplished by means of a heater or resistance coil which is placed in series with the load. This heating to the tripping point involves time to accomplish, so that the time needed for tripping is nearly inversely proportional to load. Because of this time-lag feature, the thermally-tripped breaker is not suitable for operation in case of a short circuit. Destruction of the breaker may result from short-circuit currents. For the best protection in case of a short circuit or overload the breaker which operates either thermally or magnetically should be used.

This time-lag feature of the thermal breaker is an advantage over the magnetic operation for many installations because as explained under fuses it is not necessary to trip a circuit unless the overload persists. With this breaker no unnecessary interruption will occur. The thermal type is widely used for motor protection as it will pass the heavy starting current without tripping, but will provide overload protection. An advantage of any circuit breaker is that reclosing the circuit is accomplished more economically, easily, conveniently and safely than would be the case with a fuse. Generally, to reset a thermal circuit breaker or relay, it is necessary only to move the operating handle to the off position and return it to the on position. However this cannot be done immediately after tripping has taken place because the thermal mechanism is heated and has not returned to its normal condition to permit the breaker to remain in its closed position. From the above it can be seen that in the home, where generally persons unfamiliar with electrical equipment are called upon to shoot trouble, the breaker is more desirable than the fuse.

Thus, fuses and circuit breakers furnish protection for the circuit at whose source they are installed. Their capacities are in accordance with the circuit conductor sizes. They are located at points wherever conductor sizes decrease in accordance with requirements of the National Electrical Code.

Questions

1. What is a fuse?
2. How many types of fuses are used commonly on interior wiring systems?
3. On what principle does a fuse operate?
4. How much current above its rating is needed to blow a fuse?
5. What is a circuit breaker?
6. For what purpose is a circuit breaker used?
7. On what principle does a circuit breaker operate?
8. What are some of the advantages and disadvantages of fuses and circuit breakers?

References

Craft - American Electricians' Handbook
National Electrical Code
Abbot - National Electrical Code Handbook
Richter - Practical Electrical Wiring
Gebert - N.E.C. Blueprint Reading
Watt & Summers - Handbook of National Electrical Code
Square "D" Electric Company
"Pass & Seymour" Electric Company

Trouble Hunting

TESTING FUSES

Whenever interruptions occur on fuse-protected circuits the blown fuse must be replaced in order to restore service. In the case of plug fuses it generally is possible to determine their condition by inspection. If the fuse is unblown the window is clear and the link is visible in the window. If the fuse is blown the inner surface of the window is blackened. However, in some isolated cases the link may open at some other point except in the window thereby leaving no indication that it is open. In this case testing becomes necessary.

In addition to the ordinary window type plug there is a type containing several links which is the equivalent of several fuses contained in one case. In the tope of the case of this plug is a small neon lamp. As this top is moved into position to put a new link into use the lamp moves with it. This lamp which is always visible to the observer is connected across the fuse link which is in the circuit. While the link remains intact the lamp does not glow. But when the link opens the circuit voltage is impressed across the open link thereby causing the lamp to glow and indicating the blown fuse.

Also in the case of cartridge fuses, means are used in some cases to indicate when a link is broken. Two of these indicators are the neon lamp as described in the plug fuse and the paper cap or plug in the outer surface of the cartridge which is expelled when the blowing takes place.

When no indicating device is used testing for blown fuses becomes necessary. This testing may be done by means of a test lamp, a voltage tester, or a voltmeter. Connection of the testing device is made to the load side of the fuses as shown in Fig. 1 to determine if the circuit is opened or closed.

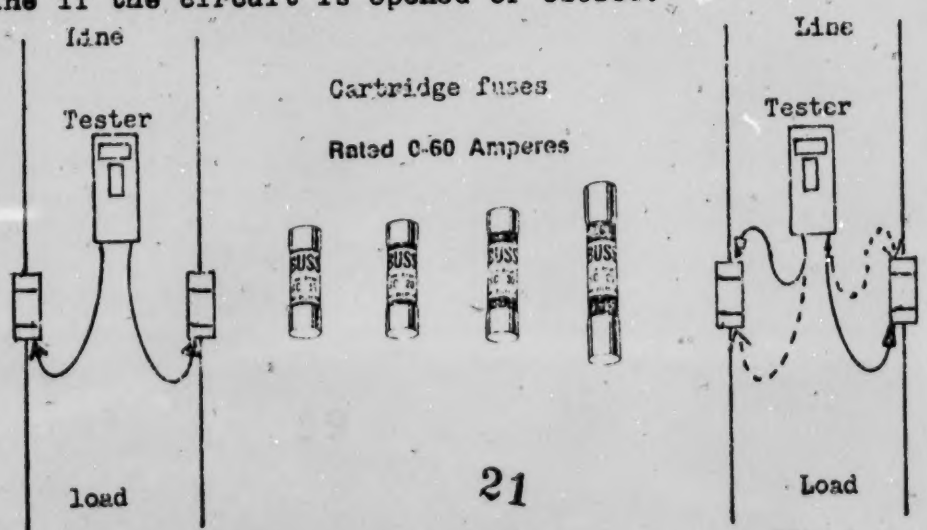


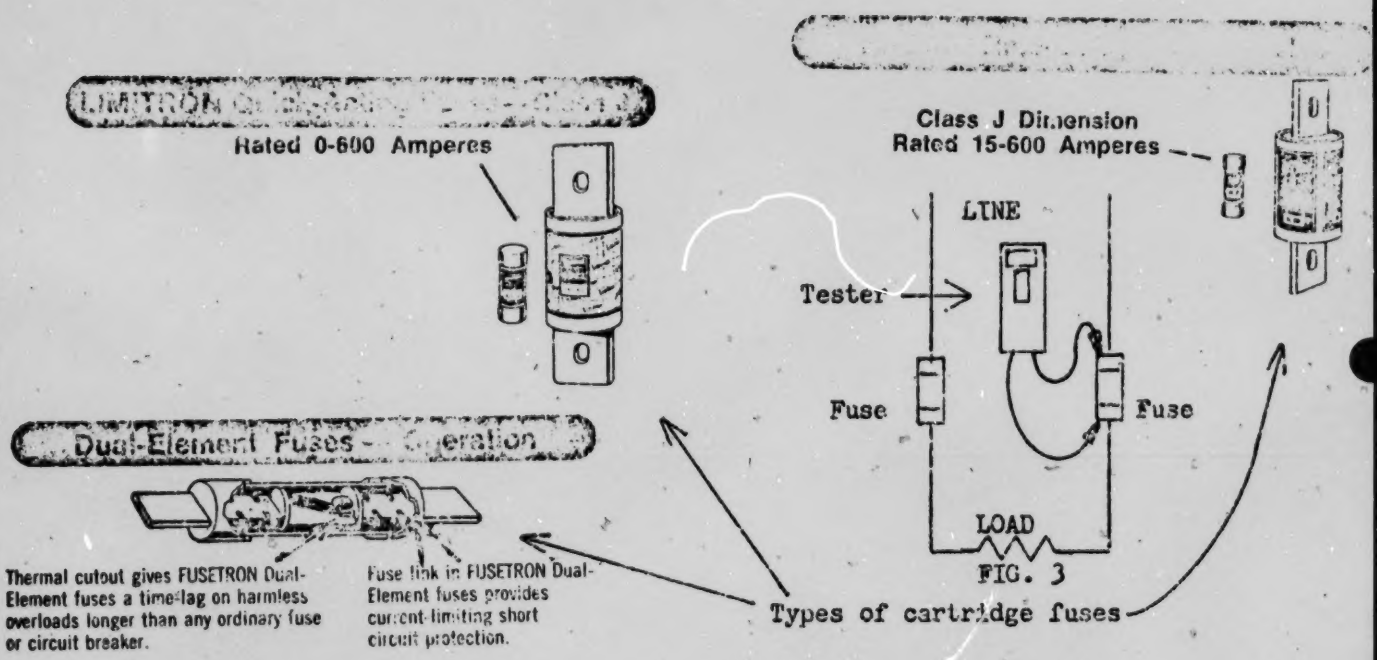
FIG. 1

FIG. 2

To locate the blown fuse check each side of the fuses as shown in Fig. 2.

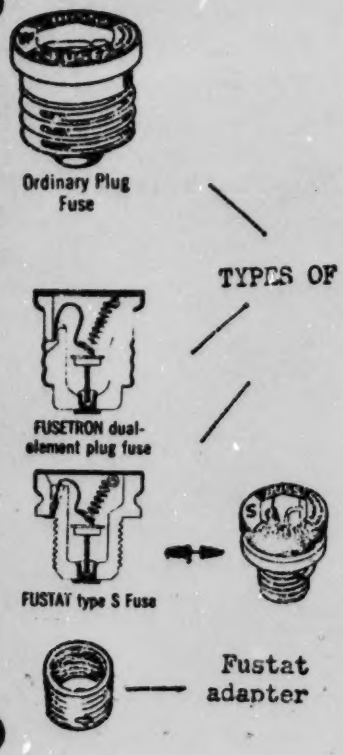
With the solid-line connections, operation of the test device indicates #2 fuse OK while with the dotted-line connection operation indicates #1 fuse OK. In each case the other fuse is the one which is faulty.

Another method of checking is shown in Fig. 3.


Rated 0-600 Amperes
Class J Dimension
Rated 15-600 Amperes
LINE
Tester
Fuse
Fuse
LOAD
Dual-Element Fuses - Operation
Thermal cutout gives FUSETRON Dual-Element fuses a time-lag on harmless overloads longer than any ordinary fuse or circuit breaker.
Fuse link in FUSETRON Dual-Element fuses provides current-limiting short circuit protection.
Types of cartridge fuses
FIG. 3

In this case if the load device is connected to the circuit the test device will operate across the blown fuse. Care should be exercised to use a testing device the voltage rating of which is sufficient for whatever voltage may be encountered in the test.

When removed from the test block a fuse may be tested by any one of several means as a test lamp, an ohmmeter, a magneto, or a megger. One form of test lamp is shown in Fig. 4.



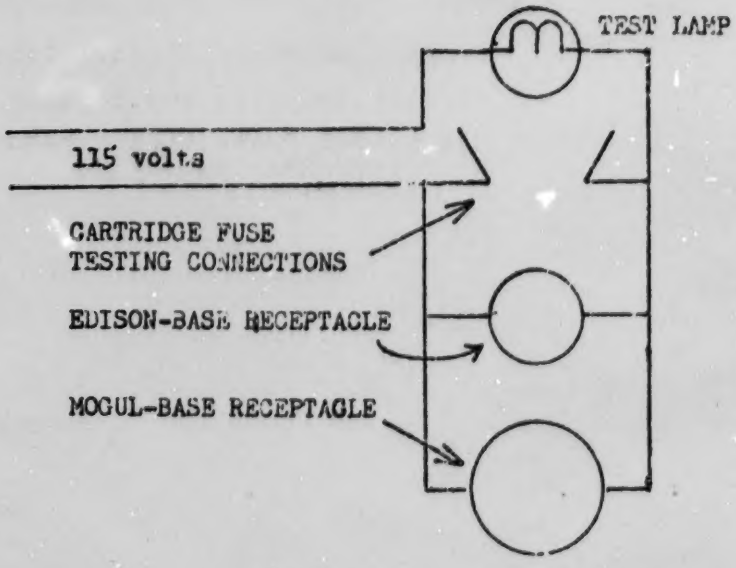


FIG. 4

Any receptacle used in Fig. 4 should have the screw shell threads flattened so that the fuse body may be inserted easily for test without threading it in.

Questions

1. Is it necessary to test all plug fuses for open or blown condition?
2. Is it necessary to test all cartridge fuses for open or blown conditions?
3. What other means are available for determining their conditions?
4. What means except test lamps may be used to test fuses in a fuse block?
5. By what means, except test lamps, may fuses be tested after removal from fuse block?

References

Croft - American Electricians' Handbook

Circuit Troubles and Testing - Croft

Electrical Protection Handbook, Bussman Manufacturing, 1975 Edition

Illumination

THE INCANDESCENT LAMP

Principles of Its Operation

In previous studies you discovered that when electricity flowed through a conductor, heat was produced. If a conductor is heated to an exceedingly high temperature, it becomes white-hot or incandescent and light is produced. Tungsten is the material most widely used today for producing light by incandescence. Other materials such as carbon, osmium and tantalum were used in the evolutionary development of the incandescent lampl but tungsten possesses the best all-around combination of favorable qualities. Osmium and tantalum were never commercially acceptable due to the extreme fragility of the filaments. Carbon lamps, quite inefficient, were used until the development of the tungsten filament.

The filament of the early tungsten lamp was operated in a vacuum at a higher temperature than the old carbon lamp, and consequently had a higher efficiency. However, the bulb gradually blackened due to depositing upon it of evaporated tungsten from the hot filament. Later, the development of the gas-filled bulb under a pressure approximating that of the atmosphere helped this situation. An inert gas such as nitrogen, by its pressure retards (but does not prevent) the evaporation of the tungsten, thus permitting higher filament temperatures resulting in greater light with no reduction in lamp life. Although the introduction of the gas retarded the evaporation of the filament, it produced an undesirable cooling of the filament through convection currents. To offset this effect, the filament was coiled like a closely wound spring. With such a design, the surface exposed to the cooling effects of the circulating gas is greatly reduced and as a result a much more efficient lamp was obtained. Also, this construction was stronger, and the adjacent turns of the coil helped to keep each other heated. From that point on, the lamp was rapidly improved. A new filament was later developed in which the former coil was coiled again, resulting in much greater efficiency. This is known as the coiled coil lamp.

There are three principal parts of any incandescent lamp; namely, the filament, the base and the enclosing envelope or bulb.

Filament

The filament made of tungsten wire in the form of a helical spring is connected at each end to "lead-in" wires which conduct the electricity from the base to the filament. The filament is

supported by molybdenum wires anchored in a glass button. In order that the lead-in wires may have substantially the same coefficient of expansion as glass, a series of metals are used for them. Nickel is used from the filament to the point where the lead-in wire enters a glass stem. At this point Dumet wire (consisting of a core of nickel-iron alloy and a sleeve of copper) passes through the glass stem, and copper is used from the stem to the base.

The filament is made in various shapes and dimensions depending upon the service for which the lamp is to be used. Although most lamps are designed to be burned in any position, some are restricted in this use.

Base

The base is made of brass in various sizes and types. These are made in five sizes; namely, miniature, candelabra, intermediate, medium and mogul. The most common type of base is the Edison screw base having a thread for insertion into a socket.

Other types of bases are: the bayonet, prefocus and bipost.

Bulb

Every incandescent lamp must have an enclosing glass envelope or bulb to prevent air from reaching the hot filament. The oxygen in the air would cause the filament to burn up almost instantly.

The bulbs of the incandescent lamps are made in various shapes, depending largely upon the application. The different shapes are designated by letters - examples: - A for standard, S for straight side, PS for pear shape, F for flame, G for round or globular and I for tubular.

The glass bulb may be clear, colored, inside frosted, or coated inside or outside with reflecting or diffusing material. The most widely used bulb is the inside frosted. This consists of a very light acid etching applied to the inner surface of a clear bulb. This etching diffuses the direct rays from the filament with a loss of less than one percent.

Another kind of finish is used on bulbs to produce colored or tinted light. One form consists of a sprayed coating applied either inside or outside of the bulb. Colored light, also, may be produced by the use of bulbs made of colored glass.

The daylight incandescent lamp uses a bulb of special blue glass, which may be either clear or inside frosted. This special glass absorbs the red and yellow rays, producing a light more nearly approaching that of average daylight in color. However, there is a 35% reduction in light output from these lamps.

In recent years the development of metallic, reflective coatings either inside or outside of the bulb has resulted in several new, very useful types of lamps.

The outside coating is usually of silver. These are known as the silvered bowl lamps. The coating shields the brilliant filament and forms a highly efficient reflecting surface for indirect lighting. This silver coating neither dulls nor tarnishes throughout the life of the lamp.

Inside reflective coatings (do not confuse this with the inside frosted lamp) are generally of aluminum or silver. Examples of these are the all-glass sealed beam headlamp, projector and reflector lamps. Each combines lamp, lens and reflector all in one hermetically sealed unit. The projector and reflector lamps have a wide range of spotlighting and floodlighting uses. As spotlights they may be used for special merchandising displays in stores. As flood lights they may be used to flood light the outside of a building or even as general illumination in a yard or driveway. When these lamps are used outdoors they must have heat resisting glass bulbs. These are but a few of the many and varied applications for projector and reflector lamps.

Characteristics

The worth of any electric light source of a given wattage is measured by how much light it gives off and how long it continues to produce it.

For incandescent lamps 750 to 1000 hours have become accepted as a good economic life for general service lamps such as we use in our homes.

It is very important that voltage ratings on lamps agree with the voltage of the circuit on which the lamp is used. Over-voltage of the circuit will cause shortened lamp life with a higher light output; while under-voltage will lengthen lamp life but will result in lower light output. Thus 1% over-voltage produces a 3% increase change in light output. Conversely, 1% under-voltage produces a 3% decrease in light output. With respect to lamp life, a 1% increase in voltage reduces lamp life by 8%. A 1% decrease in voltage increases lamp life by 20%.

Where excessive vibration is encountered - (lamp fastened directly to a machine, lamps on drop cords used in auto service stations and repair shops); rough service incandescent lamps should be used. Since rough service lamps do not produce as much light as corresponding general lighting lamps; their use should be restricted to locations where operating conditions warrant their use. A 100 watt general service lamp emits 1620 lumens of light, while the 100 watt rough service lamp will emit only 1200 lumens of light.

The upward flow of heated gas in the gas-filled Type C incandescent lamp produces a hot spot on the surface of the bulb above the filament. Water falling on this spot is apt to cause the bulb to crack. For this reason Type C lamps should not be used outdoors. For outdoor service, use the vacuum Type B lamp.

The characteristics just mentioned are unfavorable ones for incandescent lamps. However, they have many favorable characteristics which are:

1. Unity power factor.
2. Operation directly from standard electric circuits (no auxiliary equipment required as in the case of electric discharge lamps).
3. Wide range of filament shapes and light distribution.
4. Wide range of interchangeability in standard sockets.
5. Favorable radiation characteristics within the luminous range.
6. Not affected by surrounding air temperatures (which has to be contended with in electric discharge lamps).

Questions

Multiple choice (underline correct answers)

1. A tungsten filament operating in a vacuum is designed as (a) type A, (b) type B, (c) type C incandescent lamp.

2. Introduction of a mixture of 15% nitrogen and 85% argon in the bulb produced what is known as the (a) type A, (b) type B, (c) type C.

3. Inert gases in an incandescent lamp retards (a) condensation (b) heat flow (c) evaporation of the filament (d) flow of electricity.

4. (a) Silvered bowl lamps, (b) infra-red lamps, (c) daylight lamps, (d) reflector lamps, (e) rough service lamps (f) general service lamps should be used on drop cords in auto service stations.

5. In the following list underline the 3 fundamental parts of an incandescent lamp (a) filament, (b) stem, (c) socket, (d) base, (e) arbor, (f) button, (g) lead-in wire, (h) argon gas, (i) bulb.

6. The symbol which designates the bulb shape of the common household 100 watt incandescent lamp is (a) PS (b) S (c) A (d) G (e) T.

7. The function of the bulb is to (a) protect the filament from mechanical injury, (b) prevent oxidation of the filament, (c) focus the light.

8. The number of hours which have been accepted as good economic life for general service lamps is (a) 600-7500 (b) 2000-2500 (c) 12000-15000 (d) 750-1000.

9. Under-voltage will cause (a) shortened lamp life, (b) longer lamp life, (c) higher light output.

10. The most common type of base is (a) bayonet, (b) prefocus, (c) bipost, (d) screw.

True - False Questions (Mark T or F)

11. An inert gas in a bulb permits higher filament temperatures.

12. Inside frosted bulbs absorb about 10% of the light.

13. "Par" projector spot and projector flood lamps are suitable for both outdoor and indoor use.

14. A lamp should always be burned in a circuit having the voltage which is mared on the bulb.

15. Type B lamps can be used either indoors or outdoors.

16. The coiled coil filament produces increased efficiency.

17. A "daylight" incandescent lamp produces the same amount of light as an inside frosted lamp of the same wattage, and its color is more nearly like that of daylight.

18. All types of lamps will give satisfactory service when burned either base up or base down.

19. The purpose of frosting a lamp bulb is to diffuse the light.

20. The higher the temperatures of a tungsten filament, the less is the light output.

References

Swoope's Lessons in Practical Electricity

Westinghouse - Illumination Course

American Electricians' Handbook, Croft

THE QUALITY REQUIREMENTS OF GOOD ILLUMINATION

It is not sufficient to produce a certain quantity (lumens) of light and necessarily good illumination. Nor, is it enough to say that because there is the recommended value of intensity of light (foot-candles) on a surface that the illumination is satisfactory. For example, a pair of automobile headlights, properly adjusted, will provide suitable illumination on a road, enabling the car to be driven safely. Yet these same headlights improperly adjusted will not only fail to provide the car driver with sufficient road illumination (although with the same quantity of light); but may be blinding to the driver of an approaching car. This example shows that we must have the proper control of light in order that illumination may be an aid and not a hindrance to vision. This is equally true for all our seeing tasks.

With an adequate quantity must go certain essential features of illumination quality. These include: --

1. Freedom from direct glare
2. Freedom from reflected glare
3. Good brightness ratios between the seeing task and the surroundings
4. Absence of harsh shadows
5. Color suitability

GLARE

The most harmful result from improperly controlled light is the creation of glare. In general, glare may be defined as that condition in which excessive brightness in the field of vision causes discomfort, annoyance, interference with seeing or eye fatigue. This may range from mild annoyances to acute fatigue and serious interference with the ability to see.

The mere presence of a source or surface of extremely high brightness is glaring. A bright source is frequently called a dazzling light.

Where glare exists, the iris of the eye automatically contracts to reduce the amount of light admitted. But in order to see details adjacent to the area of glare, sufficient light must be admitted to the eye. So the iris tries to expand to admit sufficient light. Thus, there is a conflict within the eye, resulting in waste of nervous energy, often causing headaches, dizziness or blurred vision.

The principle causes of glare include: --

1. Light sources and surfaces of high brightness.
2. Light sources not adaptable to the area.
3. Excessive candlepower (volume of light in the direction of the eye). Large quantities of light flux, even, when emitted from source of low brightness, may produce glare. Large windows should not be in the ordinary field of view.
4. Location of exposed light sources in the line of vision.
5. High brightness contrasts between the object and its surroundings.
6. Prolonged time of exposure to the glare sources.

Glare is commonly divided into two forms; namely, direct glare and reflected glare.

DIRECT GLARE

Direct glare usually results from an unshielded light source of high brightness located in the field of vision. Examples: - (1) An automobile mechanic working with an unshielded light bulb suspended in front of his eyes or (2) a stenographer forced to type facing an unshielded window. The natural position for the eye is horizontal. Therefore, the preponderance of light should come from above. In this position, the eyebrows and lid protect the recessed eye from excessive light. With light from other directions, the eye is not protected and there is a great likelihood of glare. Therefore, bright light sources should not be in the field of vision. To prevent direct glare, (1) shield any lamp in the field of vision and (2) mount as many as possible of the lamps at a sufficient height to keep them clear from natural lines of vision.

REFLECTED GLARE

But all glare is not direct. In the case of direct glare, the offending brightness (example - an unshielded lamp) is in the field of vision. In the case of reflected glare the offending brightness is reflected from the work in such a manner as to produce discomfort. Reflected glare is a condition which we often fail to recognize, and under which we frequently work for long periods of time. It is a dangerous condition and can result in permanent impairment of the eye. Examples of reflected glare are: - (1) the type of glare you may get from a highly polished desk top, (2) the glare of brightness a lathe operator may receive from the shiny polished surface of the "ways" of a lathe.

The effects of reflected glare can be minimized in any of several ways. For example, in the case of the glare you receive while seated at a desk with a highly polished surface; move the overhead light fixture from a position directly over the desk to a position perhaps over the top of your head, or of course by moving the desk. Also, the condition can be improved by providing the top of the desk with a diffuse or mat finish. A shiny surface can reflect bright images to the eye, but a diffuse surface cannot. Highly polished surfaces should not be in the field of vision. Another method is to decrease the brightness of the light source by using a luminaire provided with an enclosure made of diffusing material.

CONTRAST WITH BACKGROUND

If a high level of local illumination is concentrated on a work area and produces a high brightness (example - a desk lamp on top of a desk) and if there were little or not other illumination in the room (low level of general illumination): a severe strain is put on the eye when it turns away from the work towards the dimly lighted background. The reason for this discomfort is because the pupil of the eye is forced continually to adjust itself first to high levels of illumination when viewing the bright work area and then to a low level of illumination when the eye turns away from the work. Therefore, in a good lighting installation; it is extremely important that a proper balance be obtained between the general lighting of the room and supplementary, localized lighting.

Extreme contrast between a light source and its background may cause the light source to appear glaring; even though under more favorable conditions, it might be entirely satisfactory. For this reason, it is desirable to maintain backgrounds in light finishes.

TIME OF EXPOSURE

Continued or prolonged exposure to a glare-source will cause discomfort from otherwise non-objectionable objects.

HARSH SHADOWS

If a lighting system is properly designed, objects in the room will be illuminated reasonably well in all sides. However, if an object is well illuminated only on the side toward the light, the opposite side will show little detail and the effect will be characterized by harsh dark shadows.

Diffused illumination eliminates or reduces harsh dark shadows, which are very objectionable. There are several ways for obtaining diffused illumination.

(1) Enclosing the lamps with diffusing material such as opal glass globes, will help diffuse their omitted light. By using fixtures with globes made of diffusing material and properly distributing the fixtures in the room, the darker shadows will be reduced.

(2) If we paint the ceiling and walls of a room a light color, the reflection of light from them produces further diffusion and the shadows are further minimized and become unobjectionable.

(3) A still higher degree of diffusion can be obtained by using indirect lighting fixtures, in which most of the light is directed to the ceiling.

The degree of diffusion required for a particular installation depends upon the seeing tasks which must be performed in the area being lighted.

COLOR SUITABILITY

With equal foot-candles of illumination, variations in the color quality of light have little effect upon clearness and quickness of seeing. However, when color matching of discrimination is involved, it is very important that an object be viewed under illumination that will give the object its true color. This is important in clothing stores, so that the customer may be able to select a garment or fabric of a desired color. Again in a meat market, if illumination not having proper color quality is used, the meat may appear black. Again in a grocery store or restaurant, butter may appear green in color if the illumination does not possess proper color qualities.

Then too, there is the psychology of color. A feeling of coolness is produced by blue and green. Also, these colors give the illusion of space and distance. On the other hand, a feeling of warmth is produced by red and amber because these colors are associated with fire and hot deserts. "Warm" colors such as cream and buff make a room appear smaller.

Fluorescent lamps are offered in a number of shades of "White" light to meet varying lighting requirements. Example, for general manufacturing areas of a factory, the White, Cool White and Warm White shades are usually preferred. White and Warm White deliver the highest light output. Cool White provides a psychologically cool working atmosphere. For offices, cafeterias, reception and display rooms, etc., the DeLuxe Cool White is often selected for its flattering effect on people, surroundings and merchandise. The Daylight fluorescent lamp is used for applications where color matching or color discrimination are important.

In general lighting design (Unit 5) the reflectance values of ceilings, walls and other surfaces in the room depend upon the colors used and accordingly affect the utilization factor of the system. The color values not only establish the color scheme of the interior, but in a large measure the brightness ratios in the immediate seeing zones, thus affecting the "visual efficiency" of those working in the room. Eye comfort requires a light-colored environment. Dark-colored surroundings absorb and waste light, and increase shadows. But white ceilings, light colored walls, floors and equipment make seeing conditions more uniform and save light. They have psychological value, resulting in more cheerful and productive workers.

These are but a few of countless applications where there is need for light of proper color. Both the color of the light source and the color of the reflecting surfaces under illumination are vital factors in a large number of seeing tasks in industry, in the home, in restaurants and clubs, in the illumination of amusement places, in show rooms and display areas, in stores, in arts and crafts.

MIXING COLORED LIGHTS

PRIMARY COLORS OF LIGHT

As you found in Unit 1, visible light is made of six distinct colors. However, contrary to popular beliefs, the primary colors of light are red, green and blue.

ADDITIVE METHOD

Any two or more of the primary colors of light may be mixed to obtain other colors.

Examples of Mixing Colored Lights

Mixing Light Waves of	Produces
Red and Green	Yellow
Red and Blue	Magenta (bluish-red)
Green and Blue	Blue-green
Red, Green and Blue	White

Production of colored light by adding together different wave lengths of light is called the Additive Method.

THE SUBTRACTIVE METHOD

Light can be subtracted as well as added or mixed. However this method is based on a different principle. This method involves the use of filters. Various substances are used for filters such as glass, gelatin, lacquer, fabric or pigments. Colored light is produced by passing white light through a filter which absorbs all the colors except the one desired, the rays of which are transmitted. Example, if white light is passed through a red filter, red light is produced because all other colors are absorbed by the filter.

Suppose white light is made to pass through two successive filters: - first, a piece of blue-green glass and secondly, a yellow piece of glass. This is what happens: - (1) the blue-green filter absorbs all the light except blue-green rays; (2) the blue-green rays pass on to the yellow filter (yellow is a combination of red and green) where the blue is absorbed. Hence the final beam that emerges from this subtractive process is green, that being the only color which both filters have in common.

Unlike the additive process (the tendency of which is always to produce more light and to approach white); the tendency in the subtractive method of color mixing of light is to obtain less light and to approach black light.

MIXING PIGMENTS

PIGMENTS

Pigments are (1) any substances that impart color to animal or vegetable tissue or (2) any coloring material suitable for making paint and the like.

PRIMARY COLORS OF PIGMENTS

The primary colors of light are different from those of pigments. In the most elementary form the primary colors of pigments are red, yellow and blue. The reason for this difference is that when color pigments are mixed, the color is produced by a subtractive method, not an additive one. If white light strikes a red substance, every color except red is absorbed. The red is either reflected or transmitted.

Any two or more colored pigments may be mixed to give secondary or intermediate colors. The color which results will be a color that is common to both. Thus if red and yellow pigments are mixed, only the color common to both (orange) is reflected or transmitted. If the third primary pigment color blue (which has no orange) is added to red and yellow, no light is reflected or transmitted and the result is black.

EXAMPLE OF MIXING PIGMENTS

Mixing Pigment Colors of	Produces
Red and Yellow	Orange
Red and Blue	Purple
Yellow and Blue	Green
Red, Yellow and Blue	Black

"Tints"of colors are usually considered to be the result of mixing white with a color. "Shades" of color are produced by mixing black with the color.

PRODUCTION OF COLORED LIGHT

Colored light is usually produced commercially by: -

(1) Passing white light through color filters
(2) Electric Discharge Tubes (Review Unit 1)
(3) Fluorescent lamps (Review Inf. B, Unit 2) - (This is the most efficient method.)

QUESTIONS:

MULTIPLE CHOICE (Underline correct answers)

1. Mixing red and ywllow pigments produces:
   (a) black (b) orange (c) green (d) white
   (e) purple (f) blue

2. Harsh shadows can be reduced by:
   (a) using a larger wattage incandescent lamp with a clear bulb
   (b) using an indirect lighting system
   (c) painting the walls a dark brown

3. Direct glare can be reduced by:
   (a) painting the walls with white enamel paint
   (b) using a desk with a highly polished finish
   (c) shield all electric lamps

4. Where excessive brightness exists, the iris of the eye automatically:
   (a) elongates (b) changes focus (c) contracts (d) expands

5. When a ray of white light passes through a red filter, the light transmitted through it is:

(a) blue (b) green (c) red (d) white (e) black

TRUE - FALSE QUESTIONS (MARK T OR F)

6._____ If there is sufficient illumination on a desk, the amount of light in the rest of the room is not important.

7._____ The three primary pigment colors - red, green and blue.

FILL IN THE FOLLOWING SPACES

8. Name five quality characteristics of good lighting: -

(1)_____ (2)_____

(3)_____ (4)_____

(5)_____

9. The three primary colors of light are: (1)_____

(2)_____ (3)_____

10. Name three ways to reduce reflected glare:

(1)_____

(2)_____

(3)_____

REFERENCES:

Amick - Fluorescent Lighting Manual - Chapter VIII

General Electric - Fundamentals of Light & Lighting Bulletin LD-2

Manufacturers' Bulletins

Westinghouse - Illumination Course

Westinghouse - Lighting Handbook

Audels - Handbook of Practical Electricity

INTERIOR LIGHTING DESIGN

There are two methods for calculating illumination, known as the "Point-by-Point" method and the "Lumen" method. Because of the greater simplicity the "Lumen" method is the one generally used in the design of general lighting installations having a number of symmetrically positioned outlets. The "Point-by-Point" method is used when calculating the intensity at a point produced by one luminaire or by a limited number of luminaires.

Procedure for the Design of an Interior Fluorescent Lighting Installation:

1. Decide the foot-candle illumination required.
2. Select (a) the lighting system (direct, semi-direct, direct-indirect, semi-indirect, indirect) and (b) the type of Luminaire best adapted to the location.
3. Determine the proper spacings of outlets and mounting heights.
4. Select Room Index for dimensions of area.
5. Determine Reflection Factors.
6. Determine the Coefficient of Utilization.
7. Estimate Maintenance Factor (Depreciation factor)
8. Calculate the Area lighted per luminaire in Square Feet.

$$\text{Lumens} = \frac{\text{Foot-candles x Area in Square Feet}}{\text{Coefficient of Utilization x Maintenance Factor}}$$

Therefore:

$$\text{Area per Luminaire (Square Feet)} = \frac{\text{No. of lamps per luminaire x Lumens per lamp C.U. x M.F.}}{\text{Foot-candles}}$$

C.U. is the Coeffieicnt of Utilization
M.F. is the Maintenance Factor

9. Calculate the Number of Luminaires Required

$$\text{Number of Luminaires} = \frac{\text{Total Area in Square Feet}}{\text{Area (Square Feet) Lighted by One Luminaire}}$$

10. Make Layout

11. Calculate the Actual Illumination Which May Be Obtained

$$\text{Foot Candles} = \frac{\text{No. of Lamps} \times \text{Lumens Per Lamp} \times \text{C.U.} \times \text{M.F.}}{\text{Total Area in Square Feet}}$$

Step 1: Required level of illumination (Currently recommended)

Table 1

Use	Foot Candles Recommended
Machine Shops:	
Rough bench and machine work.....	50
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing.....	100
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing.....	500 (Minimum)
Extra-fine bench and machine work, grinding, fine work.....	1000 (Minimum)
Schools:	
Reading printed material.....	30 (Minimum)
Reading pencil writing.....	70
Spirit duplicated material:	
Good.....	30
Poor.....	100
Drafting, benchwork.....	100 (Minimum)
Lip reading, chalkboards, sewing.....	150 "

	Foot Candles Recommended
Offices:	
Accounting, auditing, tabulating, bookkeeping, business-machine operation, reading poor reproductions.....	150
Regular office work, reading good reproductions, reading or transcribing handwriting in hard pencil or on poor paper, active filing, mail sorting, index references.....	100
Reading high contrast or well-printed material, tasks and areas not involving critical or prolonged seeing such as conferring, interviewing, inactive files and washrooms.....	30
Residences:	
Kitchen Activities:	
Sink.....	70
Range and work surfaces.....	50
Laundry, trays, ironing board, ironer....	50
Reading and writing, including studying, books, magazines, newspapers.....	30
Desks, study.....	70
Sewing:	
Dark fabrics (fine detail, low contrast).....	200
Prolonged periods (light to medium fabrics).....	100
Occasional periods (light fabrics)....	50
General lighting: Entraces, hallways, stairways, stair landings, living room, bedroom, dining room, family room, library, game or recreation room.....	10
Kitchen, laundry, bathroom.....	30

	Foot Candles Recommended
Stores:	
Circulation areas	30
Merchandising areas:	
Service	100
Self-service	200
Showcases and wallcases:	
Service	200
Self-service	500
Feature displays:	
Service	500
Self-service	1000
Stockroom	30

EXTERIOR LIGHTING

Building:	
General Construction	10
Excavation work	2
Building exteriors - floodlighted:	
Bright surroundings:	
Light surfaces	15
Medium-light surfaces	20
Medium-dark surfaces	30
Dark surfaces	50
Dark surroundings:	
Light surfaces	5
Medium-light surfaces	10
Medium-dark surfaces	15
Dark surfaces	20

The above information was derived from Croft's "American Electricians' Handbook", and the IES "Lighting Handbook". There is, of course, many other areas in which levels of illumination is critical, and you are advised to refer to the above handbooks as a guide.

Step 2 - Lighting System and Luminaire to be Used

Just which lighting system and luminaire will be best for a given application depends upon (a) seeing tasks to be performed, (b) the construction of the room, and (c) the color of walls and ceilings, (d) whether shop, office, school, store, home, etc.

In industrial locations where appearance is not as important as maximum efficiency; open bottom reflectors, such as the R L M standard dome with reflector for incandescent lamps and R LM luminaire for fluorescent lamps, are often used. For greater diffusion, softer shadows, higher lighting level, and coolness; the fluorescent luminaire is recommended.

For commercial application such as stores, offices and schoolrooms, the appearance as well as the efficiency of the luminaire must be considered. Direct enclosing, glass (diffusing) globes for incandescent lamps and fluorescent luminaires with glass panel or louvered bottoms are often employed. Where a better quality of illumination is desirable, semi-indirect or totally indirect luminaires should be used; but they result in somewhat lower efficiencies. In a typical semi-indirect fluorescent luminaire the distribution of light upward and downward is controlled by the density of the glass panels. The luminaires used for indirect illumination may have either opaque of luminous bottoms and are made in a variety of shapes.

Other conditions influencing the choice of lighting equipment are:

(1) it should harmonize and fit in well with the surroundings.
(2) direct glare from the light source should be avoided.
(3) reflected glare from polished surfaces such as machines should be minimized.
(4) it should not produce harsh shadows.
(5) it should provide sufficient illumination for vertical or oblique surfaces, and
(6) it should be so designed that cleaning and relamping can be easily performed.

Step 3 - Proper Spacing of Outlets and Mounting Heights

In a well planned lighting installation the luminaires should be so spaced that there will be no extreme contrasts (spotty illumination). The units should never be spaced more than one and one-half times their mounting height if uniform illumination is to be obtained. Usually they are spaced less than this.

The height of the light source above the floor as governed by the height of the ceiling is usually the determining factor in the spacing of outlets.

Often the placing of outlets is influenced by the location of columns or ceiling beams which divide the room into definite sections or bays. For most bays, a symmetrical arrangement is possible and should be used.

Light distribution information furnished by the luminaire manufacturer will give the recommended ratio of maximum spacing to mounting height.

For various ceiling heights the usual and maximum spacing of outlets can be obtained from Table 2

Table 2 - SPACING OUTLETS

Ceiling Height (1)	Spacing Usual (2)	Between Outlets Maximum (For Units at Ceiling) (3)	Spacing Between Outside Outlets and Wall: Aisles or Storage Next to Walls (4)	Spacing Between Outside Outlets and Wall: Desks, Work-benches, etc. against wall (5)	Approximate Area per Outlet (At usual Spacings) (6)
Feet	(Feet)	(Feet)	Usually one-half Actual Spacing Between Units	Maximum Feet	(Square Feet)
8	7	7 1/2		3	50 - 60
9	8	8		3	60 - 70
10	9	9		3 1/2	70 - 85
11	10	10 1/2		3 1/2	85 - 100
12	10-12	12		3 1/2 - 4	100 - 150
13	10-12	13		3 1/2 - 4 1/2	100 - 150
14	10-13	15		4 - 5	100 - 170
15	10-13	17		4 - 5	100 - 170
16	10-13	19		4 - 6	100 - 170
18	10-20	21		4 - 6	100 - 400
20	18-24	24		5 - 7	300 - 500
22	20-25	27		5 - 7	400 - 600
24	20-30	30		6 - 8	400 - 900
26	25-30	33		8 - 9	600 - 900
30 & up	25-30	40		8 - 10	600 - 900

Having determined the spacing of outlets the minimum as well as the desirable mounting heights can be obtained from table 3.

Table 3 - MOUNTING HEIGHT OF LIGHTING UNITS

DIRECT LIGHTING UNITS		SEMI-INDIRECT AND INDIRECT LIGHTING UNITS			
Actual Spacing Between Units	Minimum Distance of Units from Floor	Desirable Mounting Height		Actual Spacing Between Units	Recommended Suspension Distance from ceiling
		Industrial	Commercial		
(1) (Feet)	(2) (Feet)	(3)	(4)	(5) (Feet)	(6) (Feet)
7	8	12 feet above floor - to avoid glare and still be within reach from step ladder for cleaning	The actual hanging height should be governed largely by general appearance; but particularly in offices and drafting rooms, the minimum values given in column (2) should not be exceeded	7	1 - 3
8	8½			8	1 - 3
9	9			9	1 - 3
10	10			10	1½ - 3
11	10½			11	2 - 3
12	11			12	2 - 3
14	12½			14	2½ - 4
16	14			16	3 - 4
18	15			18	3 - 4
20	16			20	4 - 5
22	18			22	4 - 5
24	20			24	4 - 6
26	21			26	4 - 6
28	22			28	5 - 7
30	24			30	5 - 7

Steps 4, 5, and 6:

The coefficient of utilization is the proportion of the light produced by the lamp which actually reaches the working plane.

$$\text{Coefficient of Utilization} = \frac{\text{Lumen Reading Working Plane}}{\text{Total Lumens Produced by the Lamp}}$$

Its value depends upon (1) the efficiency and distribution of light from luminaires, (2) the size and shape of the room, and (3) the color reflection factors of walls and ceiling.

Tables in handbooks and information supplied by the luminaire manufacturer give the values of coefficient of utilization for all the various types of luminaires. Pages 572 and 573 of Swoope's Lessons in Practical Electricity give a few.

But before you can determine the coefficient of utilization you must know, also, the Room Index and Reflector Factors for the walls and ceilings.

Step 4 - Room Index

As already stated the coefficient of utilization depends upon the shape and size of the room. Obviously, in a high, narrow room much of the light emitted from the luminaire strikes the side walls and some of this is absorbed by them; while in a low, large room a comparatively small percentage of the light is lost in this way. Therefore, since the proportions of a room greatly affect the amount of light falling on the working surface; tables given in handbooks, also see Pages 570 and 571 of Swoope's Lessons in Practical Electricity have been prepared to show this effect, called room index.

The room index is based on the width and length of the room together with the ceiling height or the mounting height of the fixtures. In the case of direct and semi-direct types of luminaires, mounting height (the distance from floor to luminaire is used in determining room index. The reason for this is, because in this type of unit the ceiling has little effect since practically all the light is directed downward. In the case of semi-indirect and indirect types of luminaires; use the ceiling height in determining room index, because the ceiling in effect becomes the light source.

Step 5 - Reflector Factors

Not only does the coefficient of utilization depend upon (a) the efficiency of the luminaire and (b) the size and shape of the room; but also upon the color and reflector factors of walls and ceilings.

Every surface reflects a certain percentage of the light which strikes it, depending upon its texture and color. Table 4 gives the precentage of light reflected (reflection factors) from typical walls and ceilings usually found in commercial and industrial interiors, and will be a guide in selecting the coefficient of utilization. With a low reflection factor, a surface will reflect fewer lumens; while a higher reflection factor will result in more lumens reaching the working plane.

Table 4 - REFLECTION FACTORS OF COMMON ROOM SURFACES AND COLORS

Reflection Factor (percent)	Material	Paints
75 or more	White asbestos-finish Accoustic-Celetex	All whites, light ivory cream
40 - 75	All white finish accoustical material	Light grey, light buff, light yellow, very light green
40 - 60	Unfinished accoustical materials. Light buff tile, natural finish maple, birch, mahogany, walnut	Light green, light blue, medium gray, salmon
20 - 40	Light, mottled floor covering light oak	Medium brown, green, blue gray
1 - 20	Dark walnut, oak, mahogany, majority of floor tiles	

The character and condition of walls and ceilings have a direct bearing upon the illumination obtained from any installation of luminaires, because the ceilings and walls are really secondary sources reflecting the light that reaches them. From Table 4, it is obvious that these surfaces be as light in color as practicable. In general all ceilings and friezes should reflect not less than 65 per cent; walls from 30 to 50 per cent; and desk, tables, etc., not over 25 per cent of the light striking them.

Window shades usually represent a considerable portion of the room surface and their color should be carefully considered to provide the 30 to 50 per cent suggested for the walls. However, in most lighting designs, it is assumed that windows have no shades. Since window glass reflects very little light back into the room, window areas are equivalent to very dark walls.

Step 6 - Coefficient of Utilization

Knowing the room index and the reflector factors, you can determine from tables, the utilization factor for a given luminaire. (Each luminaire in itself has a certain efficiency).

Step 7 - Maintenance Factor (Depreciation Factor)

It is impossible to maintain a lighting system at its initial or maximum value. Good housekeeping and a planned program of maintenance can slow down the rate of depreciation, but never eliminate it. Depreciation represents an additional loss which you must allow for in your original calculations.

The depreciation is due to four causes: --

(1) Loss of lumens in the light source, due to aging of the lamp. Prompt replacement of burned-out lamps or very old and blackened lamps is highly desirable.

(2) Accumulation of dust, dirt, insects on the luminaire and the lamps. This effect will vary widely depending upon atmospheric conditions. Due to their construction and shape some luminaires collect dust and dirt more readily than others and thus have different operating efficiencies. Many manufacturers suggest depreciation factors for their luminaires. Example, they may give a value of 0.75, 0.65 and 0.55 for a certain semi-indirect fluorescent luminaire. If the atmospheric conditions are reasonably clean, it is safe to assume the middle value of 0.65. If the area were air conditioned and no open windows, the 0.75 value could be used.

(3) Once freshly-painted walls and ceilings with time become dirty and darken; thereby, increasing the absorption of lumens striking them. Periodic cleaning and painting will reduce this loss. If the system is indirect or semi-indirect the decrease in efficiency of the lighting system is much greater than where the direct type of luminaire is used.

(4) The actual voltage at the socket rarely agrees with the lamp design voltage.

Maintenance factors vary widely. But, in general, the maintenance factor will range from 0.50 to 0.75 for most interiors.

In order to perform Steps 8 and 11 you must know the lumen output of various lamps. These values are given in handbooks and manufacturer's data. A few are given in Tables 5 and 6. It must be borne in mind that these values are constantly changing due to improvements being made in the lamps.

Table 5 - FLUORESCENT LAMP (STANDARD COOL WHITE) LUMEN OUTPUT

LAMP	LUMENS OUTPUT
14 Watt - 15 inch preheat cathode	540
15 Watt - 18 inch " "	730
20 Watt - 24 inch " "	1000
25 Watt - 33 inch " "	1600
40 Watt - 48 inch " "	2500
90 Watt - 60 inch " "	5150
22 Watt - 8 1/4 inch Dia. Circline	930
32 Watt - 12 inch Dia. Circline	1550
48 Inch Slimline - 425 Ma - 38 Watts	2300
64 Inch Slimline - 200 Ma - 37 Watts	2450
72 Inch Slimline - 425 Ma - 55 Watts	3600
96 Inch Slimline - 425 Ma - 74 Watts	5050
40 Watt - 60 Inch Instant Start (2 1/8" diameter	2400
48 Inch Rapid Start - 430 Ma - 39 Watts	2500
72 Inch Rapid Start - 800 Ma - 85 Watts	4800
96 Inch Rapid Start - 800 Ma - 105 Watts	7250

Table 6 - LUMEN OUTPUT OF STANDARD 120 VOLT INCANDESCENT LAMPS

110-115-120 Volt General Lighting (Inside-Frosted-Bulb)

Service	Approx. Lumens Output
25 Watt	265
60 Watt	835
100 Watt	1620
200 Watt	3700
300 Watt	5950
500 Watt	9900
750 Watt	15,800
1000 Watt	21,500
1500 Watt	33,000
2000 Watt	44,000

QUESTIONS

Multiple Choice (Underscore correct answers)

1. To determine the general illumination of a room the method of calculation used is

   (a) Point by point (b) Lumen (c) Slide rule

2. Coefficients of utilization are based upon:

   (a) luminaire efficiency (b) room size (c) luminaire distribution (d) amount of dirt in air (e) reflection factor of walls and ceiling (f) line voltage (g) size of lamp used

FILL IN THE BLANKS

3. Total lumens = $\frac{\text{Foot candles x (} \quad \text{)}}{\text{Coefficient of Utilization x Maintenance Factor}}$

4. Coefficient of utilization is the ratio between lumens reaching the working plane and _____.

QUESTIONS - Continued

UNDERSCORE CORRECT ANSWERS

5. If the maximum space - mounting height ratio is exceeded, illumination will be: (a) too low (b) non-uniform (c) glaring (d) unattractive

6. Maintenance factor includes allowances for: (a) dirt accumulation on reflector and lamp (b) Luminaire losses (c) absorption by walls and ceiling (d) blackening of lamp (e) decrease in the reflectory factor of the walls and ceilings

TRUE OR FALSE (Mark T or F)

7. The proportions of a room do not have any effect upon the amount of light that strikes the working plane.

8. In designing a lighting plan one should never make compromises just to permit a symmetrical layout with respect to bay dimensions.

9. The designer of a lighting system should not allow for dirt accumulation because he has no control over this factor.

FILL IN THE BLANKS

10. An additional lumen loss keyed to the passage of time is called the _____ factor.

11. A room is 20' wide by 45' long; ceiling height is 14'. Indirect lighting is to be installed. What is the "room index"? (_____).

REFERENCES:

Amick - Fluorescent Lighting Manual Chapter VII

General Electric - Fundamentals of Light and Lighting
Bulletin L 8 - 2

Westinghouse Lighting Course

American Electricians' Handbook, Croft - 9th Edition

HOME LIGHTING

Although personal tastes play a very important part in home lighting; nevertheless, certain basic rules must be followed:

(1) The level of illumination must be high enough to enable one to see clearly without eye strain.

(2) Place shades on bare incandescent lamps.

(3) Many rooms will require two kinds of lighting, (a) general room lighting, and (b) specific (local) lighting on the seeing tasks.

Outdoor Lighting

Home lighting extends outdoors, too!. For safety and convenience; attach 150 watt projector lamp, spot or flood, to outside walls to light driveway to garage, garden or play areas.

Light post lanterns may light the walk leading to the home.

Weatherproof convenience outlets on the outside of the house are handy for decorative lighting.

Entrance

Weatherproof ceiling porch lighting fixtures or wall lanterns on each side of the door are needed to light the entrance to the home; not only for safety on the steps, but to give visitors a friendly greeting.

Illuminated house numbers help friends find your home at night. These fixtures should be switch controlled just inside the door, placed on the latch side of the door, not the hinge side.

The vestibule should be lighted by a close ceiling fixture controlled by a switch located adjacent to the entrance switch, just mentioned.

Halls

In the average hall, a lantern makes an appropriate ceiling fixture. An additional ornamental portable may be placed on a console table to give a cheerful welcome.

The up-stairs hall must be lighted for safety on the stairs. This may be accomplished by a ceiling fixture located at the head of the stairs. Hall lights should be controlled by switches located on each floor.

Convenience outlets should be provided to permit the use of portable lamps and appliances.

The Living Room

The living room is a place of relaxation, so it calls for light that is restful and at the same time answers the needs of each member of the family.

An abundance of portable floor and table lamps play a major role in todays well lighted living room. Their utilitarian purpose is to supply convenient light for close work. Their decorative purpose is to bring to a room a feeling of comfort, of restful cheer and welcome. A well lighted living room supplies useful light for close work at every chair, suitable light for the television, the desk and the piano and ever in keeping with the decoration of the room.

Floor, table, or pin-to-wall lamps, provided with shades under which are diffusers or reflector bowls should be placed at each chair. Use 50-150 watt threelite bulbs. Use table, desk or swing-arm floor lamp at desks used for casual study or short periods of work. The swing-arm floor lamp permits closing of the desk when not in use. Portable wall lamps may also be used at desks. Wall fluorescent lamps using two-20 watt fluorescent lamps provide as much as 80 foot candles of soft light over the desk surface.

Wall Valance Lights provide good general lighting for a living room. The wall valance light gives:

(1) Dramatic general room lighting.

(2) The appearance of more space.

(3) Color and patterns of draperies, wallpaper, etc. are high-lighted.

(4) An enlivening, cheerful, glamourous atmosphere.

(5) Light reflections from wall and ceiling to supplement light from portable floor and table lamps - thereby providing a greater level of illumination for the room.

A minimum of 16 feet of valance, preferably across one entire wall should be used. Behind the valance, which may be as deep as 10 inches; use 20, 25 or 40 watt fluorescent lamps, end-to-end to fit the length. A common valance is 6 inches wide by 6 to 10 inches high. Wall valances may be in two or more segments; none less than 4 feet long. Valance is placed across an outside wall over doors and windows. The distance from the top of the valance to the ceiling should not be much less than 10 inches.

Lighted Cornices, similar to valances, are mounted at ceiling height. They give an illusion of height to low-ceiling rooms.

Television Viewing

Do not make the mistake of darkening the room for television as for a movie. This is wrong because the television screen is both brighter and smaller than a movie screen. The use of proper lighting will avoid eyestrain and fatigue caused by the strong contrast between the bright television tube and dark surrounding areas. Furthermore, you won't bump into and fall over furniture when you move about.

What to Use:

Some of the floor or table lamps normally in the room may be used. These may be turned to low or medium level, if they are three-lite bulbs. Torcheres with opaque reflectors may be used. A television lamp placed on the top of the television is suitable. Wall-to-wall valance lighting is effective when located back of the viewer. Place lamps so direct light from lamp does not fall on television tube. Locate floor or table lamps some distance away at left and right of set. Avoid exceptionally bright spots of light on walls near the set. Avoid bright lamp shades.

In the living room there must be a sufficient number of convenience outlets to assure effective lighting from portable lamps and also for the use of electric appliances. Every wall space large enough for a piece of furniture should contain a duplex receptacle. For long wall space duplex outlets should be placed so that no point is more than six feet from an outlet.

At least part of these receptacles should be controlled by switches at all entrances to the room.

Sun Porch

Since the sun porch usually has many windows, it is necessary to light with a ceiling fixture rather than wall brackets. This ceiling light must be controlled by a switch at the doorway.

Portable lamps are just as essential for reading, sewing, and decoration as in the living room. Therefore, provide a sufficient number of convenience outlets.

The Dining Alcove

There should be a ceiling fixture, of the suspended type or close-to-ceiling type, to direct light down on the table. A combination of a ceiling fixture over table and lighted wall valance or fluorescent wall bracket gives sparkle on the table and soft relaxing light for the room. Wall valance adds to a pleasing atmosphere. A fluorescent wall bracket mounted about midway between the top of the buffet and the ceiling adds charm to the room.

The wall valance may be similar to wall valance lighting in the living room, but not across an entire wall. It should be at least 35 inches long. Use a fluroescent lamp, at least one 25-watt. Preferably, place the balance on wall opposite living room valance unit. This will compliment and extend the living room. Where conditions prevent this, place it on another wall or over window.

The ceiling fixture should be controlled by a switch at each entrance to the room.

Provide ample convenience outlets or an appliance circuit having No. 12 copper conductors.

The Kitchen

Good lighting will make a kitchen bright, streamlined and efficient for your work; and produce a cheerful atmosphere giving sense of cleanliness.

A center ceiling fixture, controlled by switches at each entrance, is used to provide general room lighting. Use a close-to-ceiling fixture. A fixture with a minimum of three 20 watt or two 25 watt fluorescent lamps is desirable. Also, the Circline Fluorescent with one 22 and one 32 watt lamp, is quite popular for the center ceiling light.

A second, smaller ceiling unit should be mounted over the sink and in back of the fancy shielding board between the cabinets on each side of the sink. This fixture may be attached to the ceiling or recessed in the ceiling. A fluorescent wall fixture may be used instead, if the sink is not in front of a window.

Undercabinet Fixture

For preparing food at a work counter, undercabinet fixtures are desirable. You can get 25 foot candles of light on your work by using a 20 watt fluorescent lamp for each 25 inches to 30 inches length of work counter. Attach the fluorescent fixture to the wall near the bottom edge of the upper cabinet; or on the underside of the cabinet near its front edge. Height above the floor should not be more than 58 inches nor less than 50 inches.

Wall Fixtures

A shielded unit should be mounted over the range to illuminate the whole range top, if such is not provided with the range. A shielded fixture with a 25 or 40 watt fluorescent lamp is suitable. Mount the fixture on the wall above the range with bottom edge of fixture no more than 58 inches above floor.

A wall fixture may be used above a sink where wall space permits.

For appliances such as iron, percolator, toaster, mixer, etc., provide convenience outlets at a height of 42 inches from the floor on a separate appliance circuit having No. 12 copper conductors.

Electric clock outlets may be six to eight feet above the floor.

An automatic clothes washer should be placed on a separate circuit having No. 12 copper conductors.

An electric dishwasher requires a separate circuit of proper wire sizes.

The electric range requires a separate circuit of proper wire sizes.

At the rear entrance a weatherproof lantern is needed on the outside of the house and should be controlled by a switch just inside the door.

The Bedroom

Permanent wall brackets are not recommended for general lighting in bedrooms because they too often limit the arrangement of furniture. The use of a ceiling fixture for general lighting and portable lamps for local lighting allows flexibility in furniture arrangement. The ceiling fixture is usually close to the ceiling and use soft atmosphere giving lamps. The enclosed glass globe or shade is of pleasing color and shape.

A valance may be mounted over the window. The valance is not essential to meet minimum lighting requirements but adds to the charm of the room. The window valance is similar to that used in the Dining Alcove and should use a minimum of a 25 watt fluorescent lamp.

Dressing Table or Vanity Lamps

A pair of dressing table or vanity lamps (Height-from top of table to center of shade 15 inches) should be used on the dressing table. Shades should be white, palest ivory or champagne, so as not to distort the color of face. Use 30-70-100 three-lite frosted bubl or standard 100 watt incandescent lamp bulb. Placed 36 inches apart and six inches away from back of vanity, about 20 foot candles of illumination will provide where it is needed.

Dresser Lamps

A pair of dresser lamps (Height-top to center of shade 21 to 22 inches) should be used on the dresser. Use the same color of shade and lamp wattage as given for the dressing table lamp.

Reading in Bed

(a) Table Lamp, placed on a bedside table, may be used for reading in bed; if the lamp is tall enough and has a shade with sufficient spread to throw the light out and down on the book. Use 50-100-150 watt three-lite frosted incandescent lamp. You will have 20 to 25 foot candles of light on your reading material.

(b) Wall Lamps

A pin-to-wall lamp having a shade with diffuser or reflector bow, using a 50-100-150 watt three-lite frosted incandescent lamp may be used for reading in bed. It should be hung on the wall and centered over the head of the bed. The bottom of the shade should be about 30 inches above the top of the mattress. This will give 40 or more foot candles of illumination.

Also a wall lamp using a 25 watt or larger fluorescent lamp and mounted the same distance as for the incandescent wall lamp may be used. The fluorescent lamp will give even lighting

over large pages.

The ceiling light should be controlled by a switch at door. Provide sufficient convenience outlets.

Clothes Closets

Every clothes closet over two feet in depth should be lighted. To do this, a socket is placed inside and just above the door so that the light is thrown back on the clothes. This light may be controlled by an automatic door switch or be a pull chain socket.

The Bathroom

Good lighting practice for a bathroom calls for three fixtures: - (a) one on each side of the medicine cabinet mirror and (b) one in the ceiling. Three fluorescent fixtures, each having one 14 watt fluorescent lamp, will do the job. The fixtures placed on each side of the mirror should be 60 inches from the floor to the center of the fixture. The ceiling fixture should be centered with the washbowl, 12 to 18 inches out from the mirror wall. This arrangement lights the whole room. It gives ample light on both sides of your face without shadows and on top of your head. This arrangement provides about 30 foot candles on your face.

One of the fixtures beside the mirror should have a convenience outlet for plugging in electric razors, etc.

The Basement

General lighting is mounted in the ceiling and in the stairway. It should be controlled at the head of the stairways and at any other entrances to the basement. A pilot light should be used in connection with the switch to show when the cellar lights are left burning.

Work Bench

The work bench is not generally given the consideration it deserves. An R L M fluorescent fixture with two 25 watt fluorescent lamps should be mounted above the work bench. Center the fixture of the work bench so that the lower edge of the fixture is 48 inches above the work. The 40 foot candles of light produced on the bench will make working safer, more accurate, quicker and more enjoyable.

A duplex receptacle on a separate circuit should be provided for this bench.

Laundry

The laundry requires a ceiling fixture over trays or laundry equipment. A R L M Dome Reflector with a 150 watt silvered bowl incandescent lamp or a fluorescent fixture with two 25 watt fluorescent lamps may be used. Center the fixture over the laundry and 48 inches above top of trays or laundry equipment. This will give about 40 foot candles on your work.

A separate appliance circuit with No. 12 copper conductors will be needed for the automatic washer. A 30 amphere, 3-wire receptacle with L-shaped Ground, on a separate circuit having at least No. 10 copper conductors, shall be installed for the automatic electric dryer.

The Recreation Room

Where a cellar has a recreation room, use a close-to-the-ceiling type of fixture. Portable floor and wall lamps are also used. Provide sufficient convenience outlets.

The Garage (Based on a single car size)

Projector lamps or a Post Lantern is needed outside the garage to light the driveway. Use a yellow enameled bulb in the Post Lantern sothat night flying insects will be less attracted to the light.

Inside the garage mount two porcelain keyless fixtures on the ceiling, one inside the garage doors and second fixture over the usual position of the car engine, operated by a switch at each door.

Convenience outlets are needed for a trouble lamp and battery charger. These outlets shall be protected by a GFIC as illustrated on Page of Information No. 2.

General:

Provide for:

(a) General lighting in all rooms.

(b) Local lighting for all close work.

(c) Plenty of convenience outlets - avoid the necessity for extension cords and triple tops. In living areas on unbroken wall spaces place them so that no point is more than 6 feet from an outlet, one in any unbroken wall space where furniture may be placed; one for each 4 feet of kitchen work counters and one at each other working area; and weather proof types for outdoor use (protected by GFIC).

(d) Appliance circuit in the kitchen, dining alcove and laundry (See National Electrical Code.)

(e) Special outlets for heavy duty appliances.

(f) A switch at every door - Walk in a path of light by turning lights "On" ahead, "Off" behind, as you move from room to room. Place switches at latch side of all doors. Silent switches should be supplied in all residential general lighting.

(g) Every room supplied by at least two circuits, so that failure of one circuit does not affect all the outlets in the room.

(h) Sufficient Copper - Provide enough circuits with copper conductors of sufficient current carrying capacity to give lights and appliances the full power they need for efficient operation.

(i) Remote - Control System

The remote-control system is the latest in wiring systems. It offers the greatest flexibility of control. All important lights, even though they may be a distance, can be controlled from one master station, as well as at the individual stations.

(j) No Fuse Load Centers

No fuse load centers, having circuit breakers for overload protection, does away with replacing blown fuses. Also, it prevents overfusing. The Load Center may be placed at a convenient location on the first floor, and you will not need to go down cellar to reset a circuit breaker should it trip.

QUESTIONS: Multiple Choice (Underline Correct Answers)

1. Weatherproof convenience outlets are required: (a) for the dishwasher in the kitchen (b) for the automatic electric clothes washer in the laundry (c) for convenience outlets on the outside of the house (d) for a convenience outlet in the cellar.

2. Switches should be placed:
(a) over the door (b) in the baseboard (c) on the hinge side of a door (d) on latch side of the door.

QUESTIONS (Continued)

3. The top of a valance should be located:
(a) 2 inches (b) not less than 10 inches (c) 6 inches
(d) 36 inches - from the ceiling

4. Valance lighting is used: (a) on the underside of the cabinets in kitchen (b) the outside wall of a living room (c) over an outside door to illuminate the house number (d) over an electric range.

5. (a) Silvered bowl lamps (b) Incandescent bulb (c) Fluorescent lamps (d) Reflector lamps - are used behind a valance.

6. In the dining room where wall valance lighting is employed: (a) valance should be at least 35 inches long (b) across an entire wall (c) should never be on a wall opposite the living room valance (d) never place it over a window.

7. Convenience outlets in kitchens are often placed above the floor at a height of (a) 36 inches (b) 48 inches (c) 54 inches (d) 42 inches.

8. Undercabinet fixtures are used for:
(a) valance lighting in the living room (b) over the sink
(c) under kitchen cabinets (d) over the range

9. An R. L. M. Fluorescent fixture with two 25 watt fluoreseent lamps is suitable for: (a) mounting over a work bench (b) ceiling fixture in the kitchen (c) ceiling fixture over washbowl in bathroom (d) in the laundry over the laundry equipment.

10. A 30 ampere, 3-wire receptacle with L-shaped Ground is used for: (a) Electric range (b) automatic electric washer (c) automatic electric dryer (d) on the outside of the house to insure grounding of appliances.

QUESTIONS (Continued)

TURE OR FALSE (Mark T or F)

11. In home lighting it is not necessary to take into consideration the level of illumination (foot candles) as in the case in commercial and industrial lighting.

12. Convenience outlets are never placedin halls.

13. Wall valance lighting provides good general lighting for a living room.

14. Undercabinet lighting fixtures should be mounted above the floor, not more than 58 inches nor less than 50 inches.

15. Wall fixtures for ranges should be mounted not more than 66 inches above the floor.

16. Wall brackets are highly recommended for bedroom, because they make seeing on the dresser easy.

17. Silent switches should be used for all general lighting.

REFERENCES:

Manufacturers Bulletins

General Electric Company - "See Your Home in a New Light"

American Electricians' Handbook, Croft

National Electrical Code - 1978 Edition

COMMERCIAL APPLICATIONS OF TRACTIVE ELECTROMAGNETS

There are so many commercial uses for electromagnets that it would be difficult to enumerate them all. Therefore, in this unit, only a few commercial applications will be noted and the apprentice should constantly be on the alert to observe further applications.

There are D.C. and A.C. electromagnets.

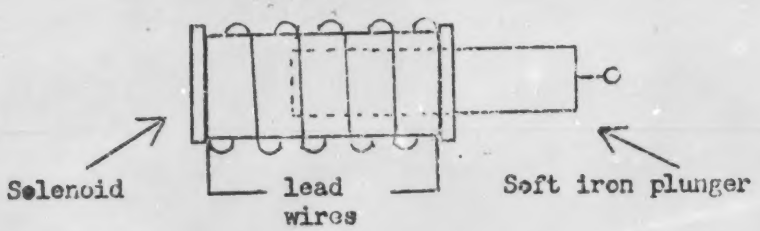
Types of Electromagnets

Electromagnets are made in different shapes according to the type of service for which they are used.

There are tractive electromagnets and portative electromagnets. A tractive electromagnet is one which pulls a load through a distance and hence does work. A portative electromagnet is one which is designed for holding or lifting only (merely intended to grip and hold in place an object brought in contact with it). Tractive electromagnets will be discussed in this lesson with the portative electromagnets in the following lesson, Information 9.

Solenoid and Plunger ("Sucking Coil")

Fig. 1



Experiment: Apply direct current to the coil in Figure 1. Bring the plunger near either end of the coil and note what happens. Does the plunger come to rest when the center of the plunger reaches the center of the solenoid?

Attach a spring balance to the plunger and note how much force is required to withdraw the plunger from the coil. The solenoid and plunger shown in Figure 1 is sometimes called a "sucking coil". This principle has many commercial applications among which are tripping circuit breakers, operating the feeding mechanism in arc lamps, operating contactors in automatic motor starters (as you will discover later), closing switches at a distance by remote control (as you will discover later), operating voltage regulating devices (Tirrel Regulator), operating valves. One example of a solenoid-operated valve is: to automatically control the supply of oil or gas to a furnace by means of a thermostat.

A Bar Electromagnet is a solenoid-and-plunger with the plunger inserted in the solenoid and rigidly fixed in position.

"Iron-clad" Solenoid and Plunger

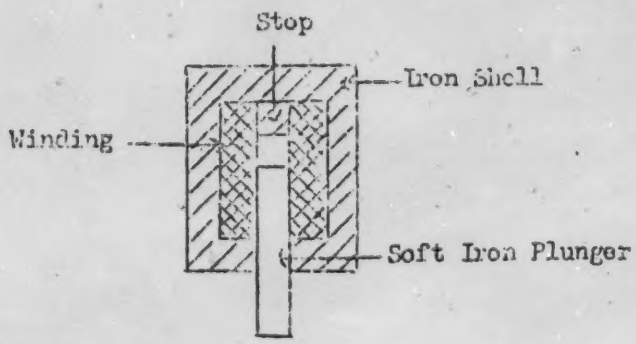


Fig. 2

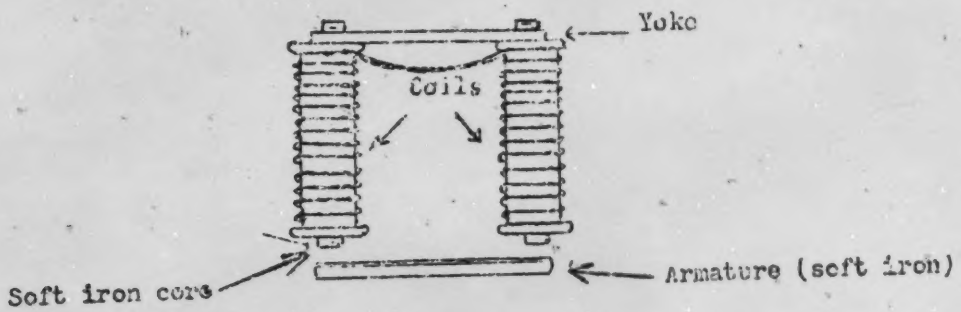
If the solenoid of Figure 1 is surrounded by an outer iron steel jacket, the solenoid can be used for tractive work. Such an arrangement is called an iron-clad solenoid. When provided with a "stop" (Figure 2) it is called a plunger electromagnet. The effect of the iron-clad feature is to confine the magnetic field within the frame. This produces a very large increase of pull as the plunger approaches the end of the stroke. An important practical application of this type of electromagnet occurs in braking of elevators

and cranes. When the power is on, the plunger of the electromagnet is pulled up thus releasing the brake. If the power for any reason fails, the plunger is no longer magnetized. The plunger drops partly due to the force of gravity and partly to the action of springs and the brake is instantly and positively set. (For further information on Solenoid Brakes see manufacturers' catalogs).

The apprentice must not confuse this type of electric brake with dynamic braking which will be considered in a later block.

Horse-Shoe Electromagnet

If a bar electromagnet is bent into a U shape we have a horse-shoe electromagnet.



This increases its affective power. Instead of forging a piece of soft iron in the shape of a horseshow, the commercial horseshoe electromagnet usually consists of three parts; namely, two iron cores connected by an iron yoke and secured by machine screws (Figure 3). When the coils are excited the iron armature is attracted. A spring (not shown) draws the armature back when the excitation is removed. Horseshoe electromagnets are used in electric bells, buzzers, telegraph relays, and sounders, etc.

Summary of Tractive Electromagnets

The question now arises: - which type of electromagnet are we to select for a specific job? The answer to this depends upon the following:

1. Whether the source of supply is direct or alternating current.

2. The distance the armature or plunger must travel.
3. Quickness of action (rate of travel); that is, whether slow speed magnet action or quick action is required.

QUALITIES OF TRACTIVE ELECTROMAGNETS

Type	Use
Solenoid and Plunger (No iron frame)	This type used only when it is desired to take advantage of its peculiar pulling characteristic.
"Iron-clad Solenoid and Plunger	(a) Is better protected mechanically. (b) Is best adapted for a long range (distance of travel) and a strong pull.
Horseshoe	(a) Quicker in action. (b) Only adapted for short ranges (distance of travel)
Plunger-electromagnet	The action of this type of electromagnet lies between the "Iron-clad" Solenoid and the Horseshoe electromagnet. It may be designed so that its action is very near to one or the other, depending on the range and dimensions of the plunger.

QUESTIONS:

1. (a) Review: When a piece of soft iron is brought near one end of a solenoid, what happens to the iron?

   (b) Review: Is the end of the iron nearest to the solenoid of the same or opposite polarity as that end of the solenoid nearest it?

   (c) Review: What is the law concerning attraction and repulsion of magnets?

QUESTIONS - Continued

2. Explain in detail why a soft iron plunger is drawn into a coil of wire carrying current.

3. Explain what part magnetic induction plays in the operation of a plunger-type electromagnet.

4. What is the difference between a "sucking coil" and a bar electromagnet?

5. Give applications where the principle of the "sucking coil" is used.

6. What is a plunger electromagnet? Draw a sketch.

7. Examine the mechanism which automatically feeds the carbons on the arc lamp used on the Blueprint machine in the drafting department. By use of a sketch, explain its operation.

8. (a) What is a colenoid brake?
   (b) Where is such a brake used?

9. What is a horseshoe electromagnet? Draw a sketch. Give commercial applications.

REFERENCES:

Industrial Electricity - Nadon and Gelmine

Elements of Electricity - William H. Timbie

American Electricians' Handbook - Croft

Swoope's Lessons in Practical Electricity - Page 201 to 204, 198-199.

Electricity One-Seven, Book One - Pages 66-100. Mileaf and Hayden, 1966 Ed.

COMMERCIAL APPLICATIONS OF PORTATIVE ELECTROMAGNETS

Portative Electromagnets

The electromagnets studied in Inf. lesson 8 were tractive electromagnets. These electromagnets perform work (pull plungers into coils, draw armatures near their poles, etc.). In other words, they pull a load through a distance and hence do work. We shall now study an electromagnet which is designed for holding or gripping in place, but not performing work. These are called Portative Electromagnets.

Iron-Clad Electromagnet

This type of electromagnet is used where a strong attraction is needed when the armature or the object to be held is in actual contact with the poles of the electromagnet. The iron-clad electromagnet shown in Figure 1 has a soft iron cylindrical core with the winding around it. This coil in turn is surrounded by an outer iron shell. Small iron-clad electromagnets are used in telephone switchboard equipment.

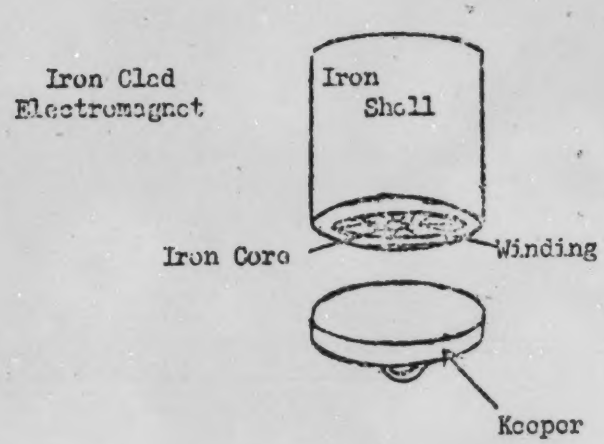


Fig. 1

Lifting Magnets

Large iron-clad electromagnets called Lifting magnets are used in the iron and steel industry for lifting rails, castings, scrap iron, for loading and unloading cars, etc.

Lifting magnets are made which are capable of lifting several tons. By using them, a saving in labor and time is effected. (See reference books for pictures showing these lifting magnets in operation). The apprentice must remember that the lifting magnet does little or no work, it merely serves as a holding device. The actual work is performed by the motor which operates the chains attached to the magnet.

Magnetic Chucks

Magnetic chucks used in machine shops for holding material on the table of surface grinders, etc., are examples of portative electromagnets. Figure 2 shows a 12-pole magnetic chuck designed and built by the State Technical School at Putnam, Conn. The cross section view AA shows two of the twelve coils. As noted on the sketch, these coils are placed on the pole pieces in the base of the magnetic chuck. As shown in the wiring diagram, the twelve coils are so connected as to form alternately north and south poles.

Coil Connectors

When used on a 110 volt line, connect coil leads 1 and 3 together and to switch contact 5, connect coil leads 2 and 4 together and to switch contact 6.

When used on a 220 volt line, connect coil leads 2 and 3 together, then coil lead 1 to switch contact 5 and coil lead 4 to switch contact 6.

Each of the coils has 990 turns of #28 enameled copper wire.

Magnetic Clutches are further examples of portative electromagnets. In the magnetic clutch, the members are engaged only when there is current flowing through the electromagnet.

Magnetic Separators

Another application of electromagnets is found in magnetic separators such as a coal sorter, grain sorter, etc. Anthracite coal as it comes from the mines of America contains some magnetic material. Therefore, to sort the coal it is sent through a magnetic separator which removes all magnetic material from the coal. Also magnetic separators are used to remove steel and iron from finely crushed ore-mixtures, to remove magnetic material from grain, to separate steel shot from molding sand, iron chips from brass of machine shop turnings, etc. The material is fed on an endless belt which passes over a magnetized pulley. The non-magnetic material

drops off while the magnetized pulley holds the magnetic material until the belt has passed the magnetized pulley. The magnetized material then drops into another hopper. The pulley has concentric coils to which the current is led by slip-rings.

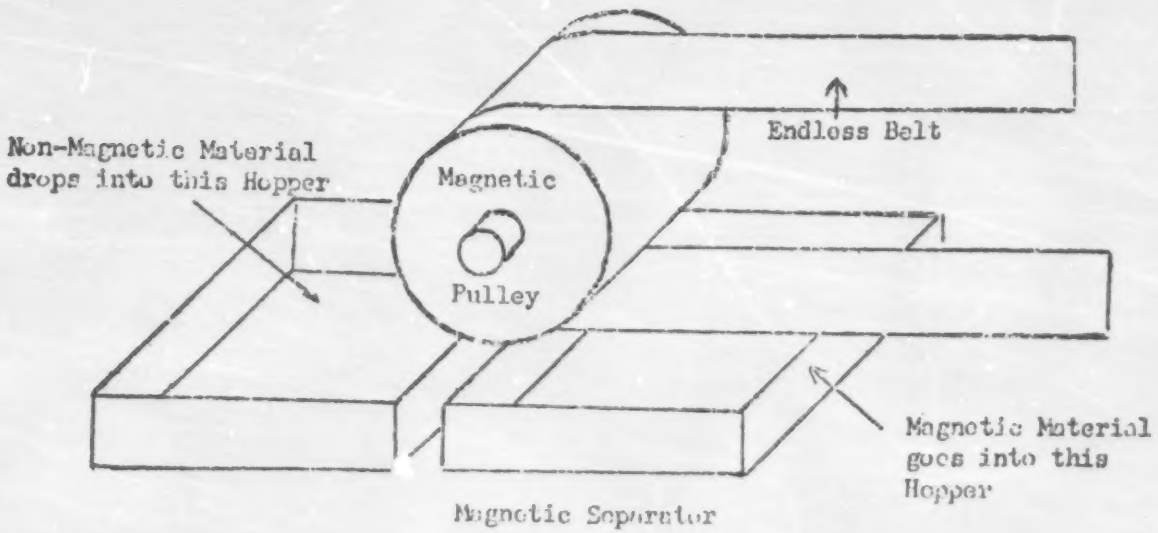
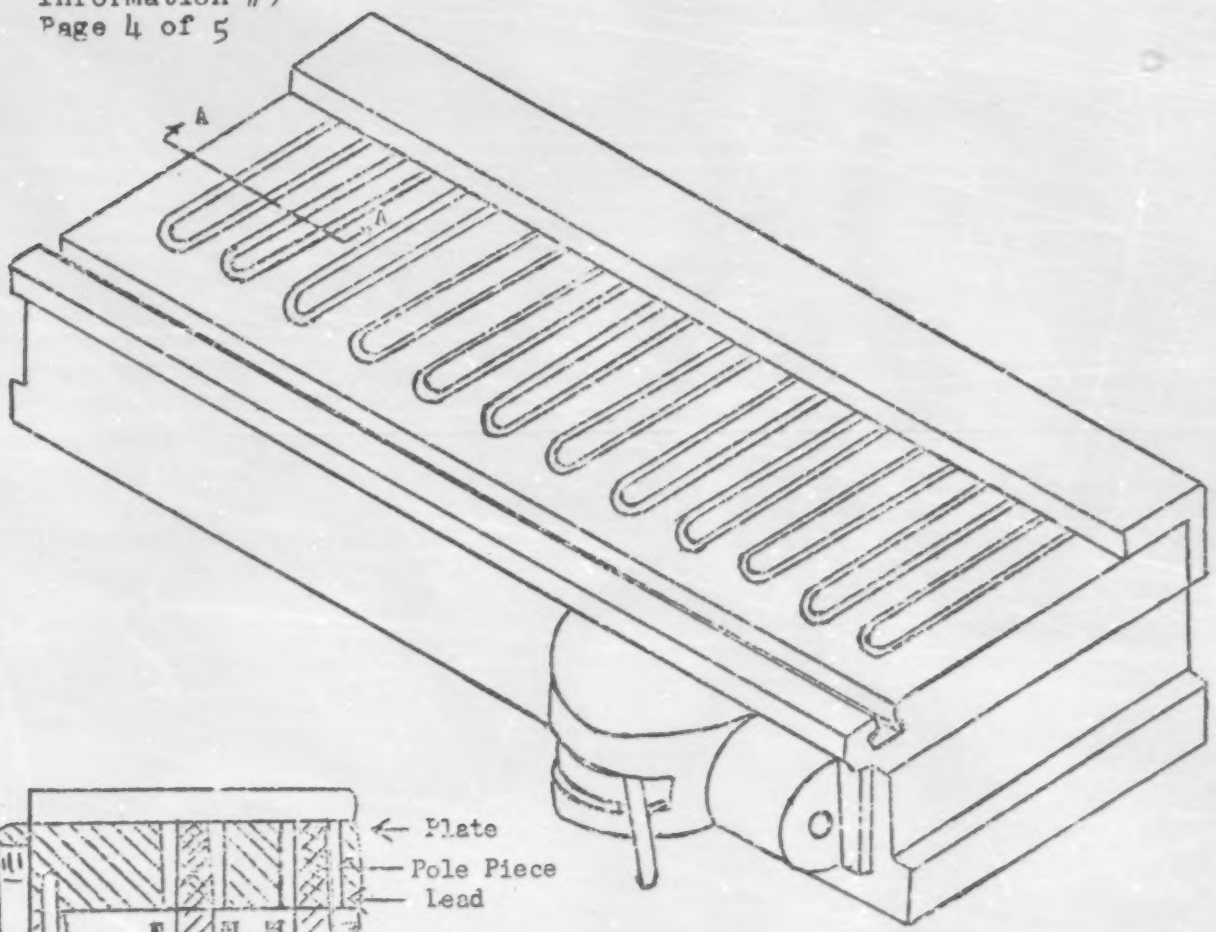
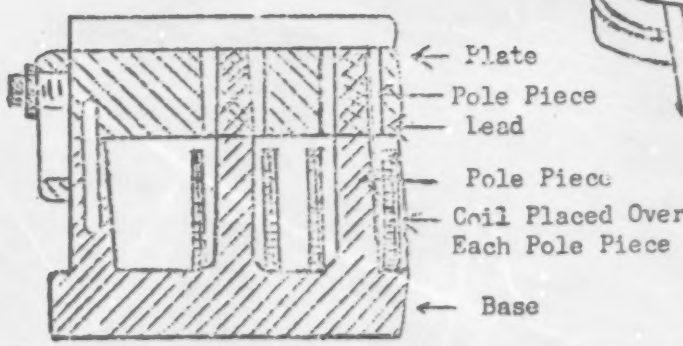


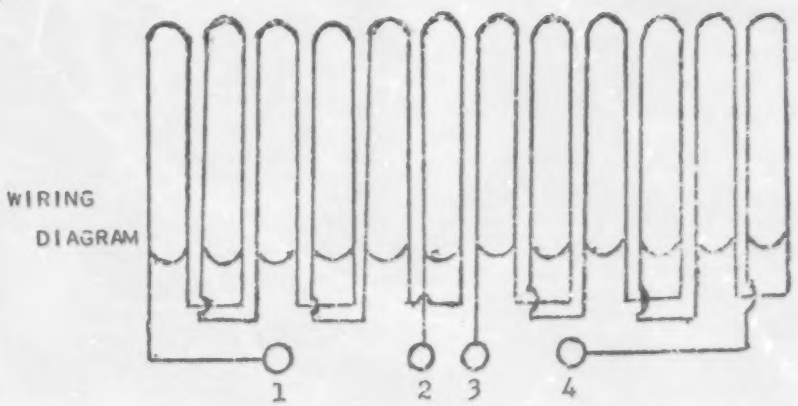
Fig. 1A

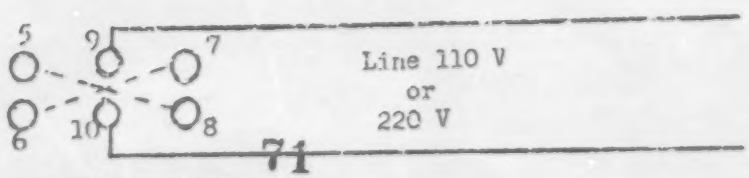




SECTION "AA"

Fig. 2





REVERSING SWITCH

12 POLE MAGNETIC
CHUCK

In this and the preceding lesson we have studied the various general types of electromagnets. However, there are many modifications of the above fundamental types. Example: Plunger electromagnets are sometimes made in the form of a horseshoe.

QUESTIONS:

1. What is an iron-clad electromagnet? Draw a sketch. Give commercial applications.
2. What is the difference in the construction of a plunger electromagnet and an iron-clad solenoid?
3. (a) What is a lifting magnet?
   (b) Where used?
4. (a) Does a plunger electromagnet perform work? Explain.
   (b) Does a horseshoe electromagnet perform work? Explain.
   (c) Does an iron-clad electromagnet perform work? Explain.
5. Could alternating current be used for lifting magnets? Explain.
6. Why are electromagnets made in so many different shapes and styles?
7. Explain the difference between the following: (Include a labeled diagram of each).
   (a) Iron-clad solenoid
   (b) Iron-clad electromagnet
   (c) Plunger electromagnet
8. (a) What is a magnetic separator?
   (b) Where used?
   (c) Explain how it operates.
9. Explain how an object being ground on a surface grinder is held in place.
10. What is a magnetic clutch?
11. What part do electromagnets play in a vibrating rectifier?

REFERENCES:

Swoope's Lessons in Practical Electricity - 5th Printing

Industrial Electricity, Nadon and Gelmine

Elements of Electricity, William H. Timbie

Electricity One-Seven, Book One, Pages 66-100, Mileaf and Hayden, 1966 Ed.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 1
Page 1 of 2

Commercial Application of Electromagnets

ELECTRIC BELL

PURPOSE:

To study the construction and operation of an electric bell.

MATERIALS USED:

Dry cell, bell wire; push button, electric bell

SKETCH:

Apprentice is to draw a labeled diagram of the electric bell properly installed in a circuit.

PROCEDURE:

Wire up the apparatus assigned to you. Connect to a dry cell and operate by means of the push button. Carefully study what happens when button is pushed.

QUESTIONS:

1. On your diagram indicate, by arrows, the path of the current through the bell.

2. Explain in detail the construction and operation of an electric bell. Include a sketch with your answer.

3. Does or does not the operation of an electric bell depend upon an electromagnet? Explain.

4. How would the following faults show themselves?
   (a) A portion of the turns shorted on the electromagnet.
   (b) The winding on the electromagnet open.
   (c) Spring contact dirty or out of adjustment.
   (d) Electromagnet short-circuited.

5. When a bell gets out of order, what is most often the trouble?

6. (a) What is a buzzer?
   (b) How does it differ from a bell?

7. What are the sources of power for electric bells?

REVIEW:

8. What are the requirements of the N.E.C. in regard to installing bell circuits?

9. Describe how to install a bell-ringing transformer: on a schematic diagram, show all material and equipment needed. State the requirements of the N.E.C.

10. May an ordinary electric bell of the vibrating type be used on either A.C. or D.C. (provided the voltage is correct in each case?) Why?

11. (a) Explain the construction and operation of the telephone bell. Include a sketch in your answer.

    References: Electricity and Electronics, Steinberg and Ford, 1973 Ed.

    (b) Will this bell operate on D.C,? Explain.

REFERENCES

American Electricians' Handbook, Croft - Pages 598-604

National Electrical Code - 1978 Edition

Swoope's Lessons in Practical Electricity, E. Hausmann

Electricity & Electronics, Steinberg & Ford, Basic 1973 Ed.

Experiment No. 2
Page 1 of 1

Commercial Application of Electromagnets

ELECTRIC DOOR-OPENER

PURPOSE:

To study the construction and operation of an electric door-opener.

MATERIALS USED:

Dry cell, bell wire, door-opener, push button.

SKETCH:

Make a labeled diagram of the door-opener properly installed in a circuit.

PROCEDURE:

Wire up the apparatus assigned to you. Connect to a dry cell and operate by means of the push button. Carefully study what happens when button is pushed.

QUESTIONS:

1. What is an electric door-opener?
2. Explain in detail the construction and operation of a door-opener. Include a sketch in your answer.
3. Give several possible reasons why a door-opener might fail to operate.
4. Draw a wiring diagram for the doorbells and openers for a three-family residence. Each apartment has two door bells (one for the front door and one for the back door). There is a door-opener on the door in the lower front hall. This is controlled by push buttons in each of the three apartments. The bells and door-opener are connected to operate on one bell-ringing transformer.
5. What part do electromagnets play in door-openers?

REFERENCES:

Handbook of Industrial Electricity, Kushlan - Pages 165-178

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 3 Commercial Application of Electromagnets
Page 1 of 1

ANNUNCIATORS

PURPOSE:

To study the operation of a simple annunciator system.

MATERIALS USED:

Annunciator, bell wire, push buttons, one electric bell, dry cell.

PROCEDURE:

Wire up the apparatus assigned you. Carefully study its construction and operation.

QUESTIONS:

1. Review:
   (a) What is an annunciator?
   (b) What are they used for?
2. Upon what does the operation of an annunciator depend?
3. Explain in detail how an annunciator works.
4. Give several applications for annunciators.
5. Make a wiring diagram of an annunciator system using a 4-drop annunciator, showing, by arrows, the path of current when one button is pressed.
6. What is the power supply for annunciators?
7. What part do electromagnets play in annunciators?

REFERENCES:

American Electricians' Handbook, Croft - Pages 9-205 and 9-206

Manufacturers' Bulletins

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 4
Page 1 of 2

Commercial Application for Electromagnets

AIR CIRCUIT-BREAKERS

PURPOSE:

To study the construction and operation of an air circuit-breaker.

MATERIALS USED:

Air circuit-breaker.

SKETCH:

The apprentice is to draw a sketch (labeling all parts) of the circuit-breaker.

PROCEDURE:

Carefully examine the construction and study the operation of one of the air overload circuit-breakers on your switch board (consult instructor).

QUESTIONS:

1. What are circuit-breakers used for?
2. Explain, in detail, the construction and operation of an air circuit-breaker. Include a sketch in your answer. In your description, answer the following:
   (a) What purpose does the trigger serve?
   (b) Is the solenoid in series or in parallel with the circuits?
   (c) What actuates the trigger?
   (d) Explain in detail how the breaker operates when the current becomes excessive.
   (e) What purpose do the copper laminations, which bridge the copper blocks, serve? Explain by use of sketch.
   (f) On closing the breaker these copper laminations press on the copper blocks making a wiping contact. Why is a wiping contact needed?
   (g) Do the carbon blocks (parallel to the copper contacts) carry much of the current or do the copper contacts carry almost all the current? If so, why?

QUESTIONS (Continued)

2. (h) When the breaker opens which breaks contact last, the copper contact or carbon blocks?

   (i) Is an arc produced when the breaker opens? If so, where?

   (j) Does any arcing take place at the copper contacts?

   (k) What purpose do the carbon contacts serve? Note: The carbon contacts are cheap and easily renewed.

3. Why are air circuit-breakers always mounted at the top of a switch board?

4. What part does an electromagnet play in the operation of an air circuit-breaker?

REFERENCES:

Handbook of Industrial Electricity, Kushlan - Pages 93-95

Manufacturers' Bulletins

Swoope's Lessons in Practical Electricity - 5th Printing

Elements of Electricity - William H. Timbie

Basic Electricity - Marcus

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 5
Page 1 of 2

Commercial Application of Electromagnets

OIL CIRCUIT BREAKERS

PURPOSE:

To study the construction and operation of an oil circuit-breaker.

MATERIALS USED:

Oil circuit-breaker.

SKETCH:

The apprentice is to draw a sketch of the oil circuit-breaker assigned to him.

PROCEDURE:

Carefully study the construction and operation of one of the oil circuit-breakers on your switch board. (Consult instructor).

QUESTIONS:

1. Is there such a thing as an air circuit-breaker for A.C. circuits?
2. Is there such a thing as an air circuit-breaker for D.C. circuits?
3. Are oil circuit-breakers used on D.C. systems?
4. What are oil circuit-breakers used for?
5. (a) Why are the terminals provided with insulating bushings?
   (b) Describe the construction of the contacts.
   (c) What houses the stationary and movable contact members?
   (d) What are the contacts immersed in?
   (e) Why is the tank removable?
   (f) For what two purposes is the oil used?
6. Explain in detail the construction and operation of an oil circuit-breaker.
7. Where are oil circuit-breakers mounted?
8. What part does an iron-clad solenoid and plunger play in an oil circuit-breaker?

REFERENCES:

Handbook of Industrial Electricity, Kushlan - Page 95

Manufacturers' Bulletins

American Electricians' Handbook, Croft - 9th Edition

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 6
Page 1 of 8

Commercial Application of Electromagnets

RELAYS

PURPOSE:

(a) To discover how a relay operates.

(b) To obtain a working knowledge of several different types of relays.

MATERIALS USED:

Relay (any simple relay), dry cell.

SKETCH:

Apprentice is to draw a sketch of the relay assigned him.

PROCEDURE:

Carefully examine the relay assigned you. Study its construction and operation.

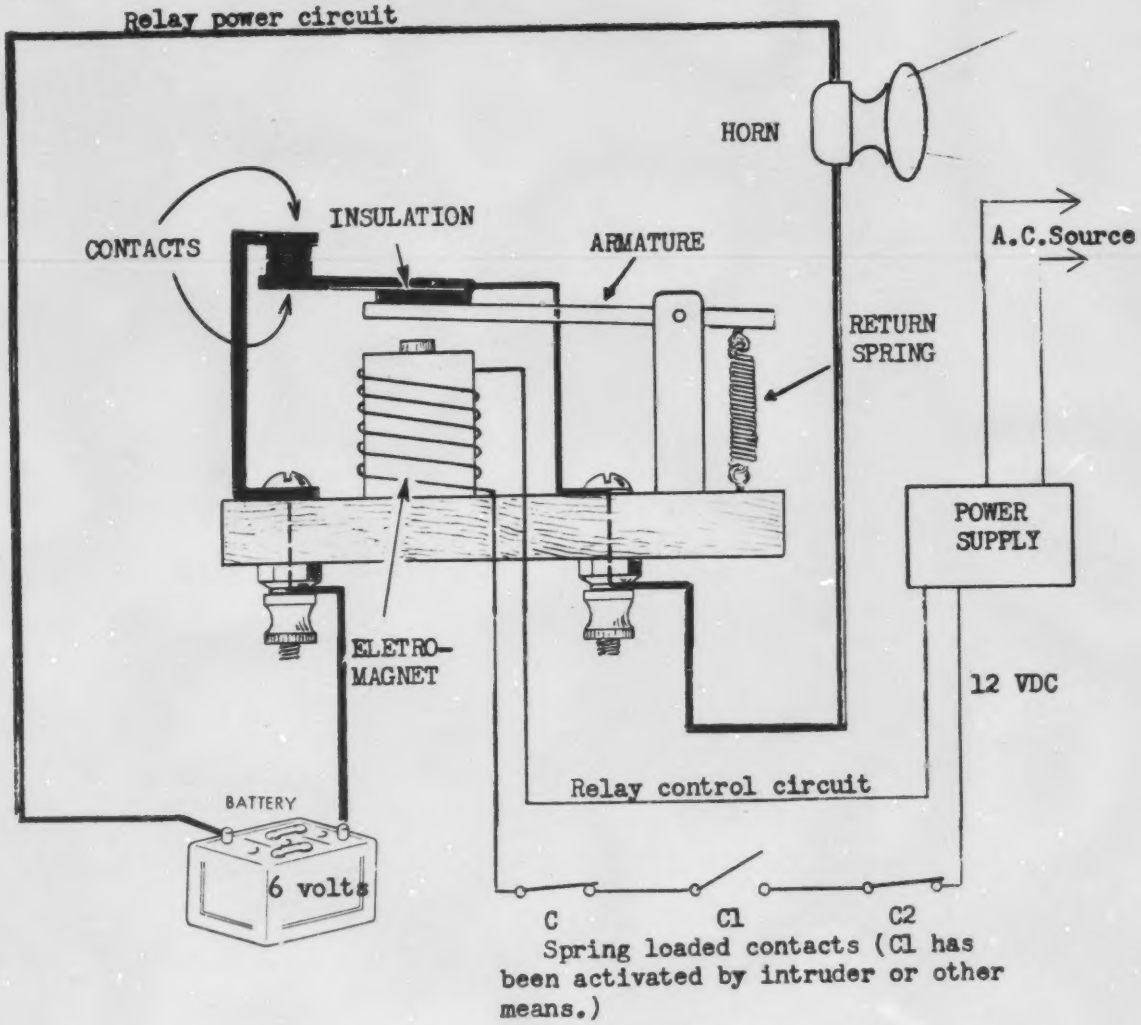
QUESTIONS:

1. What purpose does the electromagnet serve in the relay assigned you?

2. How many circuits has the relay? Draw a schematic diagram showing all circuits.

3. Explain fully the construction and operation of the relay assigned you.

Fig. 1 - Closed Circuit Alarm System.(Shown activated) The relay is not energized.



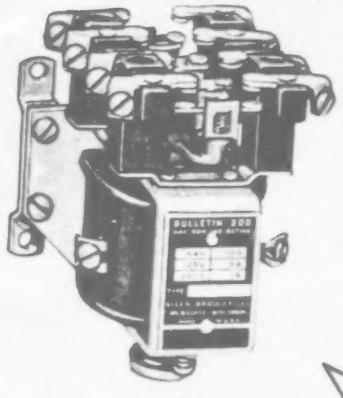
A relay is a device which closes or opens an auxiliary circuit due to a change in conditions in either the main or the auxiliary circuit.

An example is the simple relay you used on the Closed-Circuit Burglar Alarm system (Figure 1).

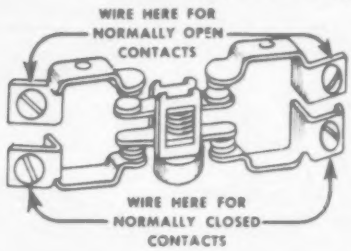
With the main circuit closed the electromagnet draws the armaturn "A" over against the action of the spring. However, when this circuit becomes open (due to the opening of the spring contacts C, C1 and C2 or some one cutting the wire in this circuit) the electromagnet is no longer energized. The spring pulls the armature back and closes the auxiliary circuit thereby causing the bell to ring.

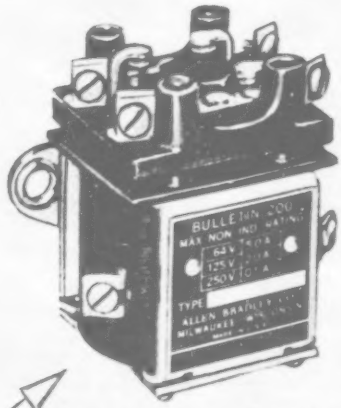
There are so many applications (and their use is constantly increasing) for relays that it would require a volume to cover this subject. Hence only a few specific instances will be noted in this unit. Further applications will be described in later blocks. In your daily work you will be constantly finding relays used. Example - You have already used relays when installing closed circuit burglar alarm systems.

Relay. (Allen-Bradley)



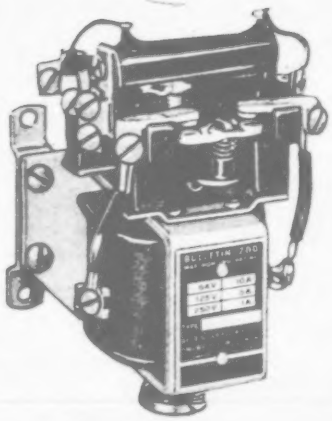
Relay contacts. (Allen-Bradley)



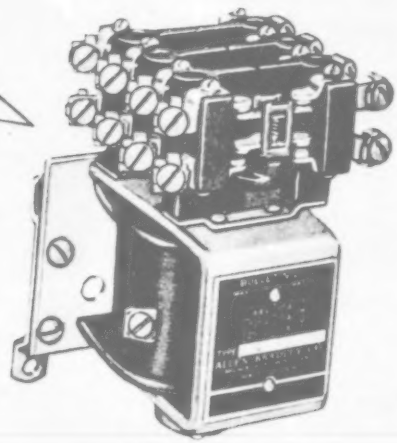


General-purpose relay. (Allen-Bradley)

EXAMPLES OF RELAYS



Thermostat relay. (Allen-Bradley)



Relay. (Allen-Bradley)

In Experiments 4 and 5 you closed the circuit breaker by hand but when the breaker is too heavy for rapid manual operation, or the voltage is high and the breaker is located a considerable distance from the point of control (remote control), the breaker is

closed by means of a solenoid or a motor. One type of solenoid mechanism consists of a powerful coil (or group of coils) which raises a plunger and closes the breaker through a main toggle and a system of links and levers. Direct current is used as the source of supply for the solenoid. The main toggle is held by a secondary toggle. The breaker is opened by tripping this secondary toggle by a coil requiring a very small amount of power. Motors are used for closing the large central station breakers.

Figure 2 shows the principle of operation of simple overcurrent relay. When the current in the main circuit becomes excessive the relay closes the auxiliary circuit. This allows current to flow from the direct current source and energizes the trip coil of the circuit breaker, which in turn opens the main circuit.

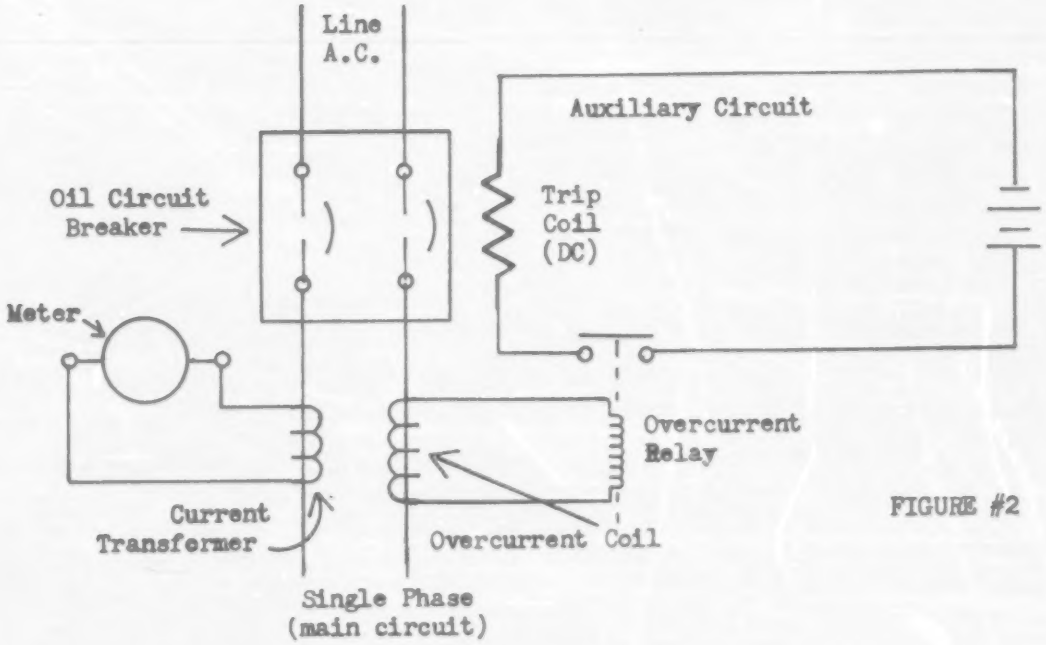


FIGURE #2

In the central power station, the sub-station, industrial establishment, etc., there are many different types of relays used. They are classified according to their construction and with respect to the duty they perform. Classifying relays according to their applications we have:

Overcurrent relays (Figure 2) which operate when the current in the protected circuit is above a predetermined value.

Undervoltage relays which operate when the voltage of a protected circuit has dropped to a dangerously low value.

Over Voltage relays which operate when the voltage of the protected circuit is above a predetermined value.

Directional relays having current and voltage elements, protect the circuit in case of a reversal of power.

Differential relays are used to protect electrical machinery from internal shorts, grounds, etc. Also they are used in protecting transmission lines making it possible to sectionalize such lines in case of trouble.

Reverse-phase relays are used (described in a later block) on polyphase motors, operating elevators, pulleys, conveyors, cranes, machine tools, etc., which should they be reversed would produce a life hazard. A reversal of phase rotation means a reversal in the direction of rotation of all polyphase motors connected to that system. This relay serves to disconnect the motor from the line in case of a reversal of phase rotation.

Phase-balance current relays are used (as you will find later) to disconnect polyphase machinery such as rotary converters and motors from the line in case of an unbalanced condition of the current flowing the phases or in case of motor attempting to run single phase.

Impedance (distance) relays are used on large complicated transmission systems. When trouble occurs at any point in the protected line, the relay operates the tripping mechanism of the switch nearest to the point of trouble thereby disconnecting the faulty line section. This relay does not supplant directional and overcurrent relays used to cut out a section developing line or ground faults where power may flow in either direction, but makes protection possible where otherwise it would be difficult or even impossible.

Low energy relays are used where only very little energy is available for operating the relay.

Direct current polarity - directional (reverse current) relays are used where a current reversal might cause considerable damage. This is true in many electro -chemical processes. The above list is by no means complete.

Classifying relays according to their method of operation, we have:

Induction type relays. Relays of this type are of a construction similar to that of an induction watthour meter. It has a movable disk placed in the magnetic field of coils carrying current and of a permanent magnet. With normal conditions in the circuit which it protects, the disk is at a standstill. With trouble on the protected circuit the disk closes the contacts of the auxiliary circuit. These relays have unusually high accuracy, sensitivity and reliability.

Plunger type relay has a solenoid-operated plunger. This relay operates on a solenoid principle studied in Information Lesson 4., of this Block. Movable contacts are attached to the plunger. When any current above a predetermined value passes through the solenoid, the contacts move to the operating position. Under normal operating conditions the force exerted by the solenoid tending to move the plunger is balanced by the restraining mechanism. A Plunger type relay is applicable where a simple, sturdy, inexpensive relay of a good degree of accuracy is required. This type is not as accurate and reliable as the induction relay.

Movable-armature type is similar in construction to a telegraph relay. This type is used mostly to protect direct current circuits.

Movable-coil type has a movable current-carrying coil placed in the field of an electromagnet. Under normal conditions the coil is at rest. With abnormal conditions on the circuit it protects, the coil moves and closes the contacts of the auxiliary circuit. This relay is used mostly for overload protection of D.C. circuits.

Temperature Relays:

(a) Over-heated bearings:

Relays are available which are used primarily for protection against over-heating of bearings. The most common type has a relay action which is largely mechanical. The relay has a bulb containing a volatile liquid. This bulb is connected by a metal tube to an expansion chamger (bellows) which actuates a switch. The bulb containing the liquid is imbedded in the bearing (or whatever is to be protected). As the temperature of the bearing rises, the liquid contained in the bulb volatilizes (at about 90°C) and creates pressure. This causes the bellows to expand which actuates a switch closing the relay coil circuit. This will perhaps ring a bell to warn the operator or in the case of automatic sub-stations trip the circuit breaker.

(b) Over-heated windings:

Since the over-heating of the winding in electrical apparatus is closely tied up with over currents, over current protection usually takes care of this. However, in large generating stations temperature indicating devices are often used to give warning when the temperature of the winding becomes such that something should be done to reduce it. Often exploring coils are embedded in the windings of these large generators. These exploring coils actuate a signal when the temperature reaches a critical point. The Westinghouse type C T relay may be used for this purpose. Its operation depends upon the current flowing through the machine for any given time and also on the temperature of the winding of the machine being protected. A sufficient change, in the resistance of the exploring coils (due to a critical rise in temperature of the winding of the machine being protected), will operate this relay. It operates on the principle of a Wheatstone Bridge. Two resistance units in the relay serve as two arms of the bridge while the two exploring coils embedded in the winding serve as the other two arms. Under normal conditions the bridge is balanced, but when the temperature of the machine reaches a certain point the unbalance in the bridge will cause sufficient current to flow through the winding of the relay to actuate it (See Westinghouse bulletins for complete details).

(c) Temperature overload relays are used for overload protection of motors.

Thermal cutouts and thermal relays are widely used for protecting alternating current motors from overloads. Because of the time lag in the heating coil, the momentary high starting current will not operate the relay. But in case of overload the relay will operate before any damage can occur in the motor.

There are many different types and makes of thermo relays on the market. The construction and operation of these relays will be explained in future lessons.

Relays are classified according to the time it takes for the relay to operate after trouble has occurred in the circuit they are protecting. They are classified as follows:

1. Instantaneous
2. Indefinite time
3. Definite time
4. Inverse time

The time it takes for the inverse time relay to open the circuit varies inversely with the amount of the overload. In other words the greater the overload the quicker relay operates. With the definite time relay, a prescribed time must always elapse before the circuit breaker is tripped. With the instantaneous types, the breaker is quickly tripped under all conditions of overcurrent. (See General Electric & Westinghouse bulletins).

QUESTIONS (Continued from Page 1)

4. What is a relay? What is it used for?

5. What are overcurrent relays used for?

6. What is the difference between an induction type relay and a plunger type relay?

7. What are undervoltage relays used for?

8. (a) Could induction relays be used to protect direct current circuits? Explain.
   (b) Could plunger type relays be used to protect either alternating or direct current circuits? Explain.

9. What is an instantaneous relay?

10. (a) What is an inverse time relay?
    (b) How does it differ from an instantaneous relay?

11. What is the difference between a definite time relay and an inverse time relay?

12. Explain what part electromagnets and relays play in the electric clock and horn system of your school.

13. Explain the operation of a Closed-Circuit Burglar Alarm using a relay. Include a schematic diagram.

14. Make a list of commercial applications of relays. Add to this list as you progress with your course.

REFERENCES:

General Electric Bulletins
Westinghouse Bulletins
Electricity, Charles A. Rinde
Basic Electricity, Marcus
Industrial Electricity, Rex Miller - 1978 Edition

Information #10
Page 1 of 8

Commercial Applications of Electromagnets

THE MAGNETIC SWITCH

Magnetic Contactors

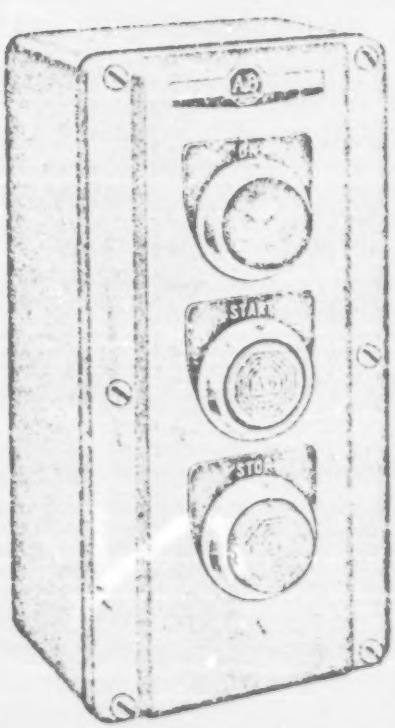
In later work you will install magnetic switches. In this type of switch the contacts are opened and closed by an electromagnet which is energized either from an independent source of power or from a tap taken in the main power supply.

By using magnetic contactors and relays in motor-starting circuits, a motor may be controlled from any convenient point away from the motor.

Magnetic controllers (for automatically starting and protecting D.C. motors) and automatic starting compensators (for automatically starting and protecting A.C. motors) use magnetically operated contactors and relays.

FULL VOLTAGE STARTING SWITCH
(ALLEN-BRADLEY)

PUSH BUTTON STATION
(ALLEN-BRADLEY)



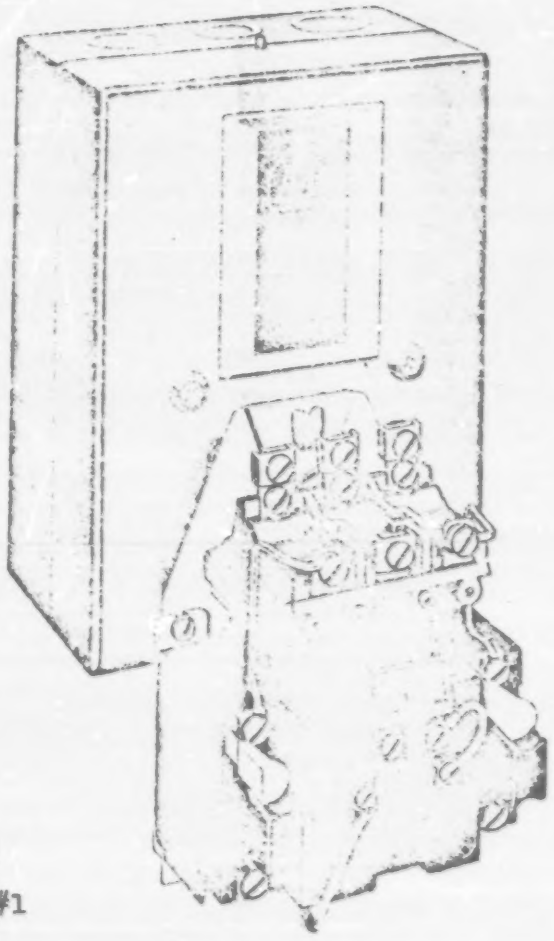
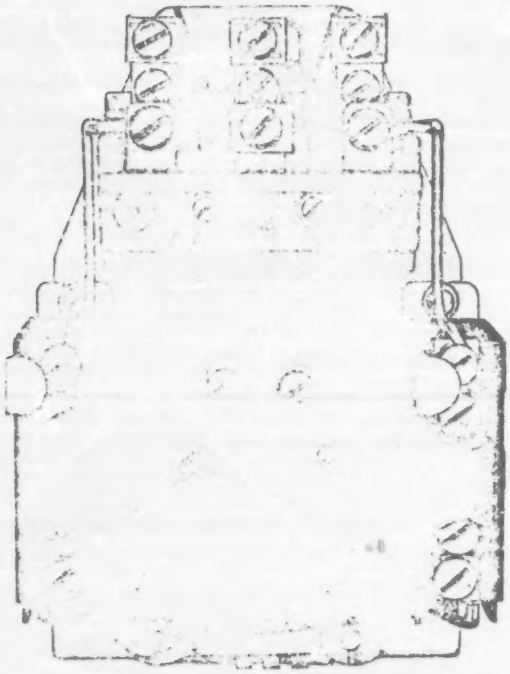
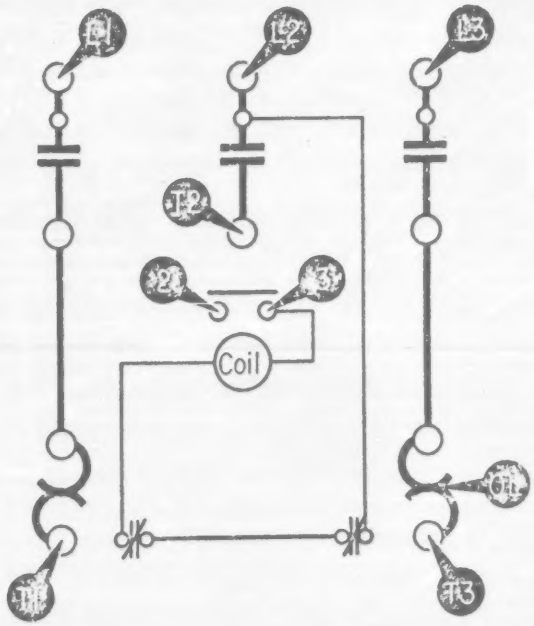


Figure #1

THE BULLETIN 709 AS REPRESENTED BY A WIRING DIAGRAM



Bulletin 709 Starter, Size 1, Form 2



Wiring Diagram For
Bulletin 709 Starter, Size 1, Form 2

Comparison of the picture and drawing shown above should help the reader become familiar with the Allen-Bradley Bulletin 709 starter as it is represented in wiring diagram form. Principal corresponding parts are labeled so that the wiring diagram can be compared with the actual starter. This should aid in visualizing the starter when studying a wiring diagram and will help in making connections when it is actually wired up. Note that the wiring diagram shows as many parts as possible in their proper relative positions. It is not necessary to show the armature and crossbar or the overload reset mechanism in the wiring diagram since these parts need not be considered from the wiring standpoint.

The Size 1 starter is shown here because all of the special wiring diagrams in this booklet use Size 1 starters as examples. The other sizes of starters have a similar appearance as the Size 1 and their principle of operation is the same. Wiring of the other sizes of starters is the same as for Size 1 although some of the connections are not physically located in the same places as on the Size 1.

Figure # 2

How some three phase magnetic starters are wired.

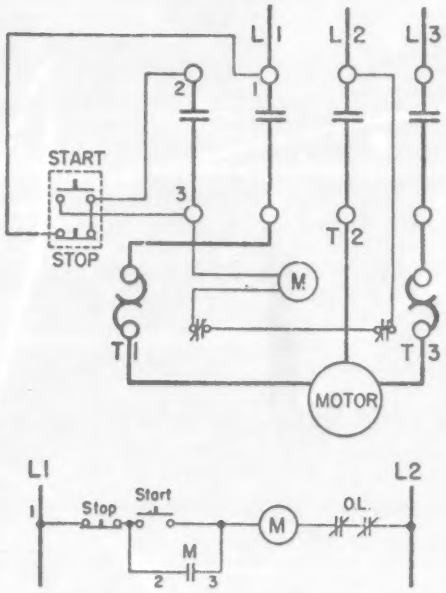


Fig. 3A Size 00

Stardard wiring with start-stop push button station.

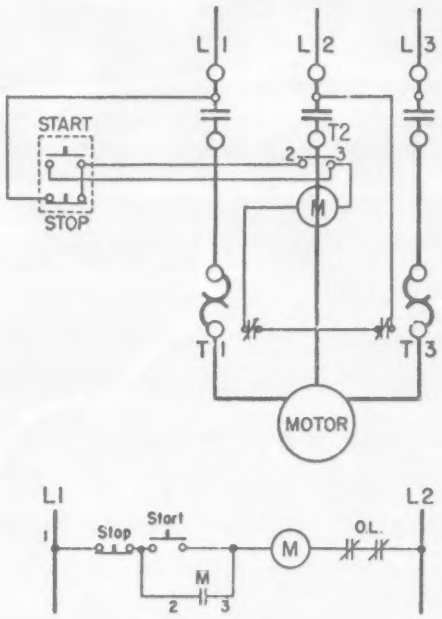


Fig. 3B Size 0,1,2,3,&4

Stardard wiring with start-stop push button station.

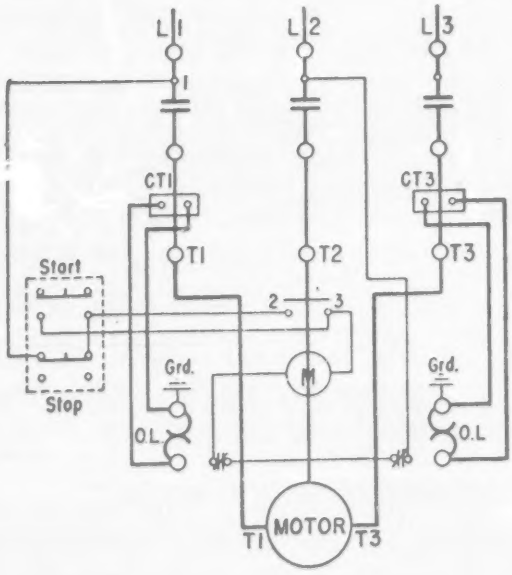


Fig. 3C Size 5

Stardard wiring with start-stop push button station. Current transformers are utilized allowing the use of size 1 overload relays. (Allen-Bradley)

Manual Push Button Line Voltage Starters

Generally, Manual push button type starters may be used to control single-phase motors up to five h.p., polyphase motors up to seven and one-half h.p. and direct current motors up to two h.p.

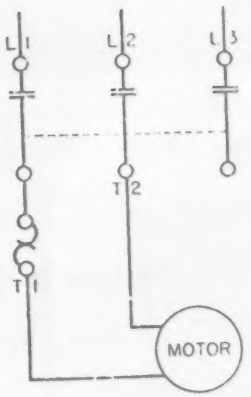
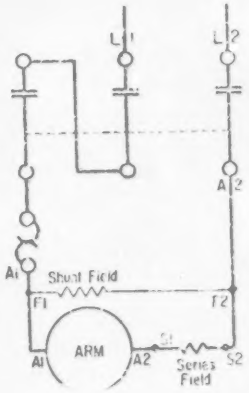


Figure # 4

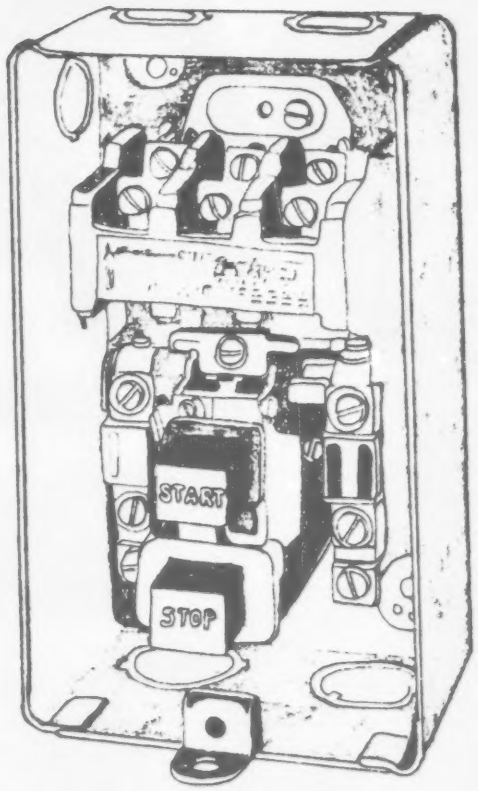
Sizes 0 & 1

Single Phase



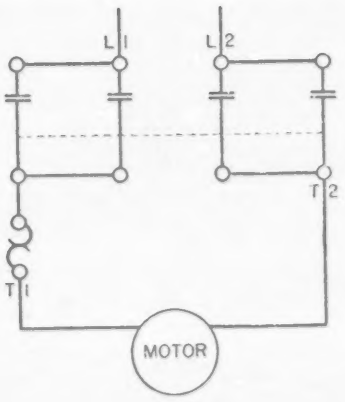
Sizes 0 & 1

Direct Current



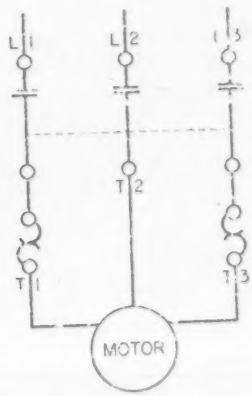
(SQUARE D CO.)

Line voltage manual starter with general purpose enclosure (cover removed).



Size 1P

Single Phase



Sizes 0 & 1

3 Phase or 2 Phase, 3 Wire

(For 2 Phase, 3 Wire, L2 and T2 are common)

Be sure to concentrate on the circuitry offered in figures 3A, 3B and 3C. Note that the main difference between them and those shown in figure 4 is the method of control. The figures 3A, #3B and 3C are remote controlled, whereas the figure 4 circuits are all controlled by a manual push button.

Overload Protection

Overload protection for motors is a must to prevent burnouts and to keep safe operating conditions prevailing.

The overload relays of a magnetic starter will prevent a motor from drawing excessive amperage which could damage motor insulation.

BIMETALLIC OVERLOAD RELAYS - These units are designed for two general applications. (Figure 5)

1. For automatic reset
2. For easy trip range adjustment of the heater to within 85 percent to 115 percent of the rating of the heater unit.

MAGNETIC OVERLOAD RELAYS - The magnetic overload relay has a coil which is designed to be placed in series with the motor. As the motor reaches an excessive current draw, the relay actuates and breaks the magnetic starter coil circuit. (See Figure 6).

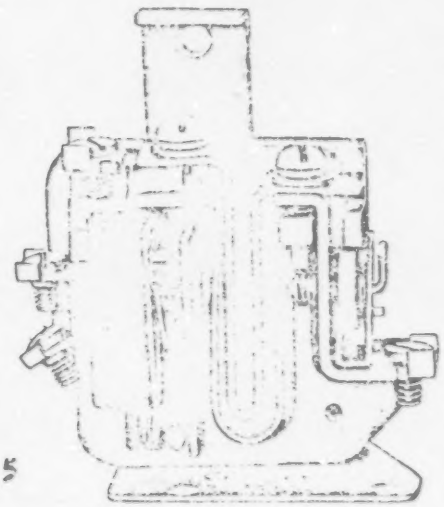


Fig. 5

(SQUARE D CO.)

Cutaway view showing construction of bimetallic overload relay.

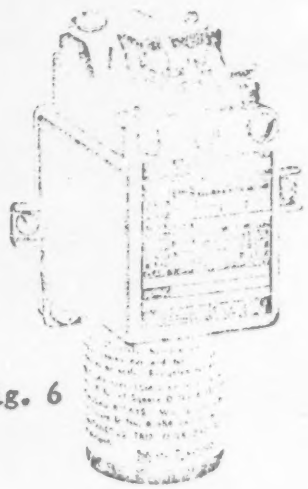


Fig. 6

(SQUARE D CO.)

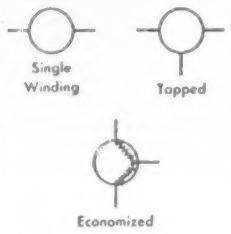
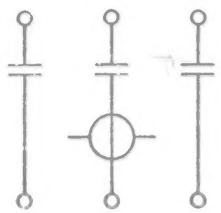
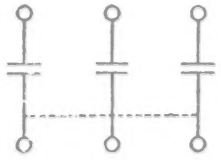
Magnetic overload relay.

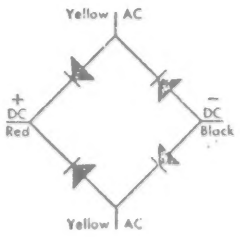
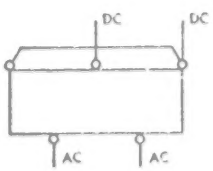
More variations of magnetic controllers and their uses will be discussed in future lessons. It would seem logical at this point to become familiar with the wiring diagram symbols. The ones most often used are as follows: (Taken from an Allen-Bradley bulletin).

Key to symbols - Although the explanations accompanying the diagrams describe the devices used, familiarity with the various symbols will lead to a quicker understanding of each circuit.

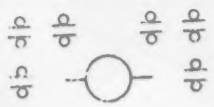
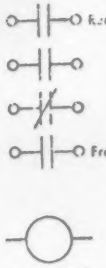
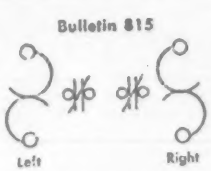
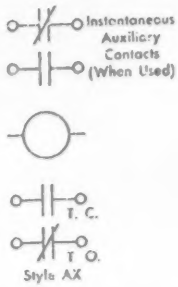
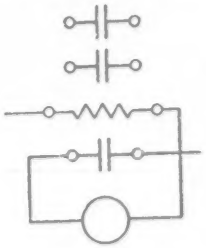
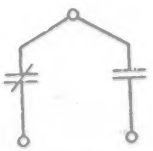
The symbols, device designations, and abbreviations are taken from the American Standard for Graphical Symbols for Electrical Diagrams, Publication #Y32.2, and have been approved as a Nema standard.

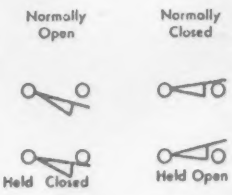
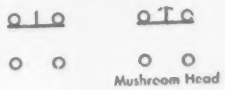
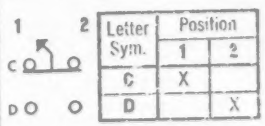
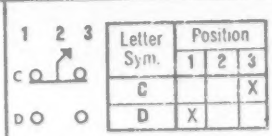
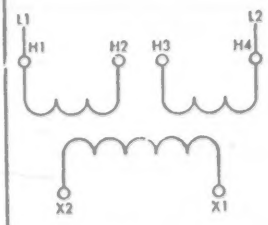
Wiring Diagram Symbols

Device		Symbol
Coils	Relay and Switch Coils	
Contacts	Normally Closed (NC)	
	Normally Open (NO)	
	Time Closing	
	Time Opening	
Contactors	AC Solenoid Type	
	Manually Operated	

Device		Symbol
Fuse	General	
Indicating Lights	General	
Motors	3 Phase Squirrel Cage Induction	
	Single Phase	
	2 Phase 4 Wire	
Rectifier	Full Wave with Color Code	
		

Wiring Diagram Symbols - (Continued)

Device		Symbol
Relays	Control Type BR	
	Control Type B	
	Thermal Overload	
	Timing (Pneumatic) ON-DELAY	
	3-Wire Thermostat Type BA	
Switches	Float Switch	 When this symbol is used on a drawing the symbol should be identified as a "float switch".

Device		Symbol
Switches	Limit Switches	
	Pressure and Temperature	When this symbol is used on a drawing the symbol should be identified as a "pressure switch" or a "temperature switch".
	Push Button Standard	
	Push Button Heavy Duty, Oiltight	
	Push Button and Jog Attachment	
	Standard Duty Selector Switch	
	Heavy Duty Selector 2-Position	 <table><tr><th>Letter Sym.</th><th colspan="2">Position</th></tr><tr><td></td><td>1</td><td>2</td></tr><tr><td>C</td><td>X</td><td></td></tr><tr><td>D</td><td></td><td>X</td></tr></table>
	Heavy Duty Selector 3-Position	 <table><tr><th>Letter Sym.</th><th colspan="3">Position</th></tr><tr><td></td><td>1</td><td>2</td><td>3</td></tr><tr><td>C</td><td></td><td></td><td>X</td></tr><tr><td>D</td><td>X</td><td></td><td></td></tr></table>
Transformer	Potential	
	Current	

QUESTIONS:

1. (a) What are magnetic contactors?
   (b) When are they used?

2. Study the construction and operation of a magnetic controller and explain how it operates (include a sketch in your answer).

3. Examine a thermo (bimetallic overload relay) cutout.
   (a) Draw a sketch showing its construction.
   (b) Explain how it operates.
   (c) Where are thermo cutouts used?

4. Explain in detail the operation of the magnetic overload relay shown in Figure 6.

5. In later experiments you will discover that, at starting, A.C. motors draw a current several times greater than their full load currents. Explain in detail why a thermal relay or a thermal cutout will allow this heavy starting current to pass, still protecting the motor against dangerous overloads which would cause a fuse to blow.

6. What part do electromagnets play in magnetic switches?

REFERENCES:

Allen Bradley Bulletins

Square D Company Bulletins

American Electricians' Handbook

Electric Motor Control - Delmar

Electric Motor Repair - Rosenberg

STACK CONTROL FOR AN OIL BURNER

Another widely used application for relays is the stack control used with oil burners. A pyrostat is installed in the stack of the boiler or furnace. The pyrostat consists of a thermostatic element (inserted in the stack in the path of hot stack gases); the thermostatic elements actuate a mechanism which opens and closes contacts of electrical circuits.

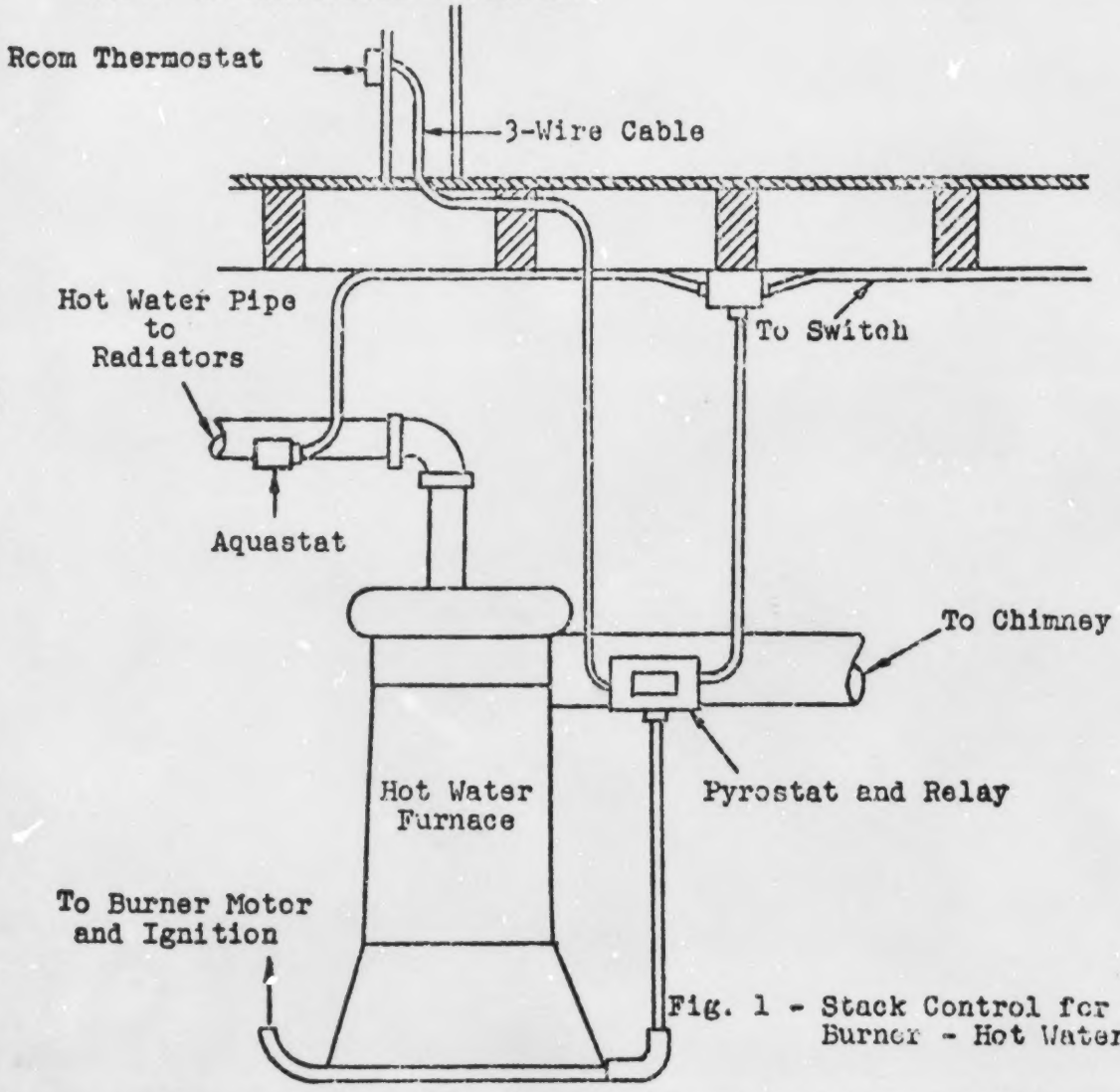


Fig. 1 - Stack Control for Oil Burner - Hot Water System

Figure 2 shows the wiring connections of a pyrostat and relay (R117 Protectorelay) manufactured by the Minneapolis-Honeywell Regulator Company. Figure 1 shows this relay on an oil burner for a hot water heating system. When the thermostat in the room calls for

heat the oil burner motor automatically starts. This feeds a mixture of oil and air under pressure to the burner. At the same time the ignition is automatically energized, oil is ignited, and combustion takes place. When the thermostat calls for less heat the oil burner is automatically shut off.

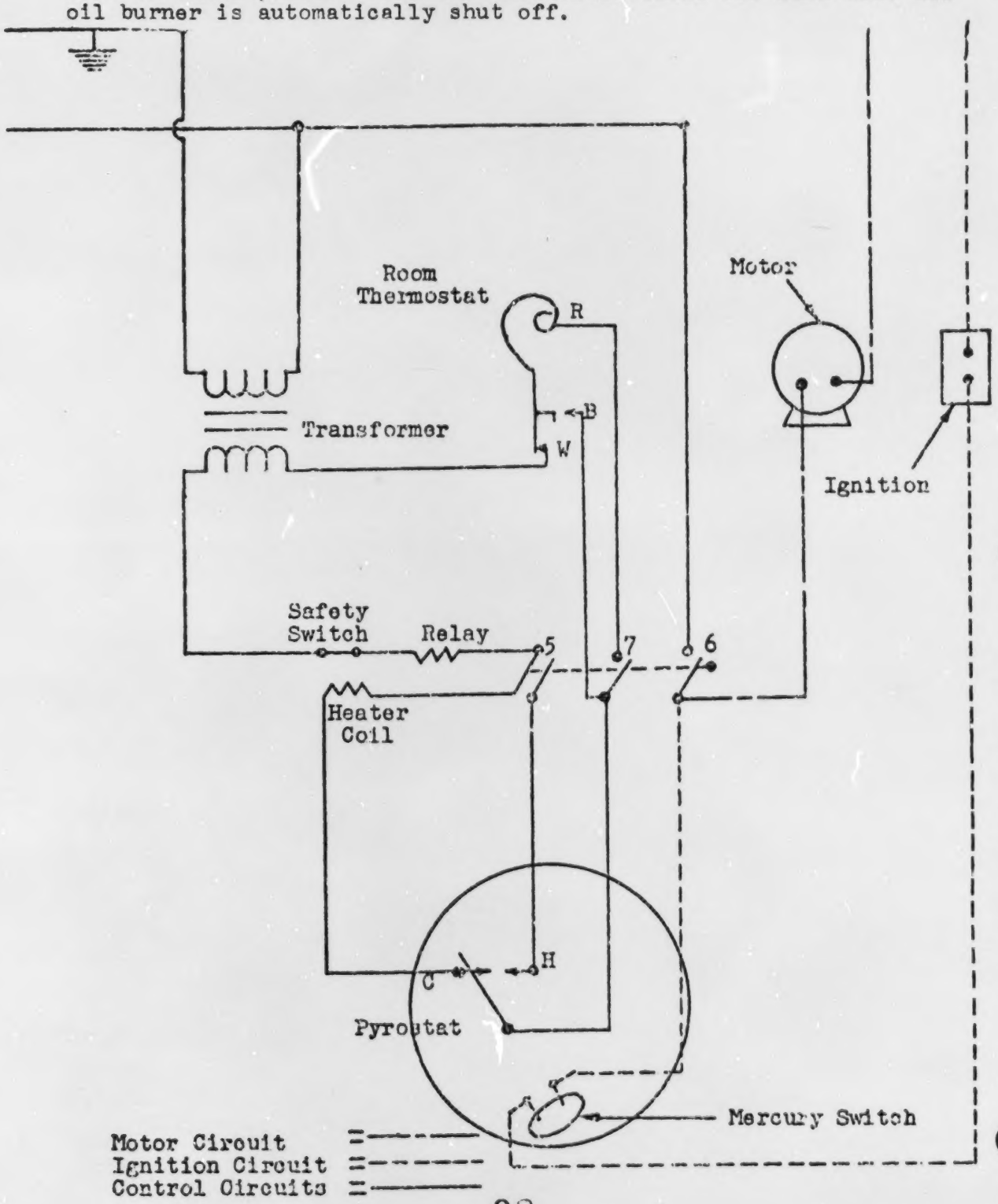


Fig. 2 - R117 Protectorelay Used on Oil Burner Installation

THERMOSTAT:

The purpose of the thermostat is to keep the room, in which it is placed, at a desired temperature (a temperature corresponding to the setting of the thermostat indicator). The thermostat consists of two dissimilar metals welded together and bent into curbed form. As you have found in your science class, metals expand when heated. However, for a given temperature rise, different metals will expand different amounts. Advantage is taken of this fact in the thermostat. Since the two metals will not expand an equal amount when the temperature of the room rises, the bimetallic strip will tend to straighten. If the strip is straightened enough, the electric circuit through it is broken. When the temperature in the room is reduced, the bimetallic strip tends to curve again and the circuit is closed.

A study of the relay circuit in Figure 2 explains how the oil burner is automatically started and stopped; also how protection is afforded in case of trouble. When the pyrostat element is cool, the cold contact (C) is closed, the hot contact (H) is open, and the mercury switch is closed.

The transformer steps the voltage down to 20 volts for the relay and thermostat circuits.

Let us now see what takes place in the pyrostat and relay when the following occurs:

(1) Thermostat Calls for Heat

When the room thermostat calls for heat it first closes its contact (W) and later its contact (B). Both contacts must be closed before the burner will start. (The (W) and the (B) contacts close at different temperatures - in some thermostats there is a difference of 1.5°F). This energizes the starting circuit for the relay and the current takes the following path: starting at the contact (W) on the thermostat it passes through the secondary of the transformer, through the safety switch contacts, through the relay coil, through the heater coil of the safety switch to the cold contact (C) of the pyrostat, from there to the contact (B) of the thermostat through the thermostat blade back to the contact (W). Since this energizes the relay coil its armature is attracted and the contacts 5, 7, and 6 are closed. Closing contact 7 completes the holding circuit. This holding circuit takes the following path: starting at the contact (W) of the thermostat, through the transformer secondary, through the safety switch contacts, through the relay coil, through the heater coil of the safety switch, through the pyrostat cold contact (C), through the relay contact 7, to the contact (R) of the thermostat, through the thermostat blade back to the contact (W). (The contact (B) has performed

its purpose in starting the burner and can now open without stopping the burner). However, once the burner stops due to the opening of the contact (W), it will not start until the contact (B) closes.

Closing the relay contacts completes the motor circuit. The motor starts and oil is forced ot the burner. At the same time that the motor circuit is completed, the ignition is energized (the circuit is completed through contact 6 and the mercury switch). The spark ignites the oil.

As stated above, the thermostatic element of the pyrostat is placed inside the stack (pipe going to the chimney) in the path of the hot stack gases. The thermostatic element is a bimetallic spring which is fastened to a shaft which actuates the pyrostat mechanism. When the stack gases rise in temperature, the spring will tend to straighten out. This will produce a tendency for the shaft to turn and actuate the pyrostat mechanism. A drop in temperature will produce a tendency for the spring to coil up.

Therefore, when combustion takes place, the warm gases going up the stack will heat the sensitive thermostatic element of the pyrostat. This immediately closes the hot contact (H) of the pyrostat mechanism, changing the path of the relay current. (The heater coil of the safety switch is shunted out). Starting at the contact (W) of the room thermostat, the path of the circuit is: through the secondary of the transformer, the safety switch contacts, relay coil, contact 5 of the relay, the hot contact (H) of the pyrostat, relay contact 7, to the contact (R) of the thermostat, through the thermostatic blade back to the contact (W).

As the stack gases continue to become hotter the action of the theremostatic strips of the pyrostat becomes greater and the cold contact (C) of the pyrostat is opened and the mercury switch breaks contact. The breaking of the mercury switch contact cuts off the ignition. The burner is now running normally. (The burner motor is still running).

(2) When Thermostat Class For Less Heat

The contact (W) on the thermostat opens. The relay coil is no longer energized and the burner is shut down.

(3) Safety Protection

(A) IF OIL DOES NOT IGNITE WHEN BURNER MOTOR STARTS.

It is evident that if there were not some form of protection when such a thing occurs, the furnace would be flooded with oil. If we review the starting operation,

we will recall that after combustion took place the warm stack gases actuated the pyrostat and its hot contact (H) was closed. When the contact (H) was closed the heater coil of the safety switch was shunted out. But if the oil does not ignite, there will be no combustion and hence no warm gases going up the stack. Therefore, the hot contact (H) of the pyrostat will not close. This will cause the current to continue to flow through the heater coil of the switch. After a predetermined length of time (usually 120 sec.) the safety switch will open (due to the action of the heat on the thermostat blade in the switch). When the switch is tripped the relay coil is no longer energized and the burner motor stops. In order to put the burner back into service after the safety switch trips, it is necessary to manually depress and release the switch button. It will be necessary to wait about five minutes for the safety switch heating element to cool before depressing the switch button.

(B) FLAME GOES OUT

If the flame goes out, the temperature of the stack gases will drop. This will almost immediately open the hot contact (H) of the pyrostat. This in turn will drop out the relay and the burner will be shut down. After a predetermined length of time (depending upon the setting of the pyrostat) the mercury tube contacts will close and then the cold conact (C) will close. If the room thermostat is still calling for heat, the burner will automatically start. If the oil does not ignite the safety switch will operate as described above. This will require manual setting. Thus we see that in case the flame goes out the burner is allowed one more chance to start automatically.

(C) ELECTRIC SUPPLY FAILS

If the electric current fails, even momentarily, the relay trips and the burner shuts down if running. When the electric current comes back on (if the pyrostat has cooled to close the cold contact (C)) the burner will start automatically.

(D) OVERHEATED FURNACES

In Figure 3 is shown a LIMIT CONTROL, as a part of the wiring diagram.

SKETCH:

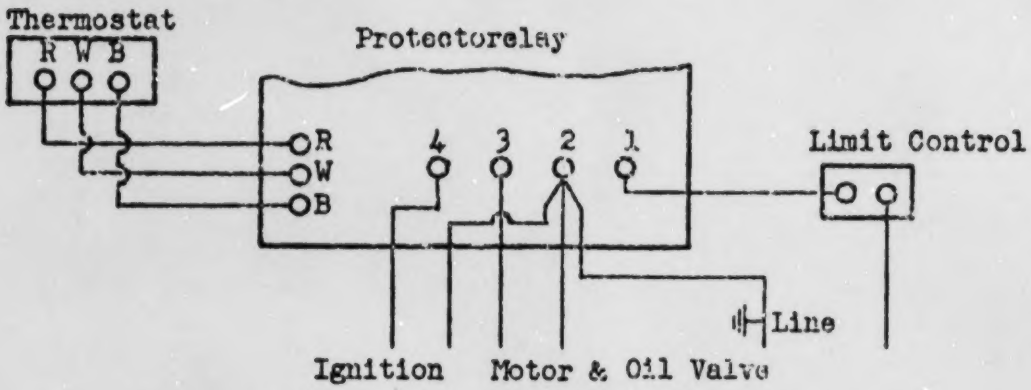


Fig. 3 - Wiring Diagram of R 117 Protectorelay

The limit control for a hot water furnace is a device called an aquastat (see Figure 1). The surface aquastat is strapped to the hot water pipe going to the radiators as shown in Figure 1. The surface squastat is used as a safety device to prevent excessive boiler water temperature. It operates by the expansion and contraction of a bimetallic (thermostatic) element. The movement of the bimetallic element actuates a mercury switch, opening the switch when the temperature of the water rises above a predetermined, safe value (usually 160 to 180°F) and closes when the temperature falls. The heat from the hot pipe reaches the bimetallic element by conduction through the back plate of the aquastat. Thus, even if the room thermostat is still calling for heat, the aquastat will operate and shut down the burner in the event that the hot water going up to the radiators has reached an excessive temperature.

In hot air furnaces the limit control is a device called an airstat. It serves to prevent the overheating of the furnace. The airstat which is mounted on the furnace casing contains a thermostatic element (bimetallic spring) and a mercury switch. The thermostat element which is inserted in the furnace casing opens the mercury switch when the temperature of the furnace rises beyond a predetermined safe value and closes when the temperature falls. Opening the mercury switch shuts down the burner.

In steam heat systems the limit control is a device called a pressuretrol. It is used to shut down the oil burner in the event that the steam pressure in the boiler exceeds a predetermined safe value. (Usually 3 to 5 pounds per sq. in.). The pressuretrol contains a set of bellows and a mercury switch. It is mounted beside the pressure gauge and in multiple with it, on the top of the furnace. The bellows actuates the mercury switch, oepning the switch when the pressure becomes excessive and closing when the pressure drops. Opening the mercury switchshuts down the burner.

Thus we see that aquastats are used with hot water furnaces to prevent excessive boiler temperatures; airstats to prevent hot air furnaces from overheating; and pressuretrols to protect a steam heating system. It is best to connect them in series with the Protectorclay as shown in Figure 3. The space marked "Limit Control" in the diagram represents an aquastat, an airstat, and a pressuretrol depending on the type of system.

SUMMARY:

After what you have leanred in Exp. 6, Inf. 10, and Inf. 11 it is evident that relays have and will continue to play an important role in the progress of the electrical industry. (1) Relays have made service reliable and continuous. This is done by automatically sectionalizing the electrical system so as to disconnect the disabled section or by automatically restoring the service after it has been accidentally interrupted. (2) Apparatus may be protected by relays. (3) Automatic control has been made possible by relays. Examples of this are the automatic starting and stopping of sub-stations and isolated hydroelectric stations. A concrete example of this is the automatic control of a sychronous converter in a railway sub-station where no attendant is required. In addition to the operation and protection of the converter, other relays control and protect the feeders. (4) Relays are serving an important role in industrial plants for protection of motors, remote control of motors, operation of electric clock systems, photoelectric cells on counting devices, automatic door openers, etc., and in countless other capacities. (5) In the home, office, store, etc., they are used on automatic heat regulators, burglar alarms, fire alarms, etc.

QUESTIONS:

1. Explain the part relays play in automatic heat regulators for oil burners. (Give a general statement).

2. Explain in detail, how an oil burner starts up when the thermostat calls for heat. Include in your answer a description of how a thermostat works, and also how a pyrostat works.

3. Explain in detail, how the oil burner automatically shuts down when the thermostat is no longer calling for heat.

4. Explain in detail, what happens if the flame should go out while the burner is running.

5. (a) Explain, in detail, how the burner is shut down in the event that the oil does not ignite.

   (b) What must be done before the burner can be started again?

6. What is an aquastat and what is it used for?

7. What is an airstat and what is it used for?

8. What is a pressuretrol and what is it used for?

9. Why is the thermostat, shown in Figure 2, so constructed that the contacts (W) and (B) operate at different temperatures? Hint: Both contacts must be closed before the burner will start.

REFERENCES:

Manufacturers' Bulletins

Penn Manual - Installation and Service for Automatic Controls

Minneapolis Honeywell, Handbook for the Installer and Serviceman.

OIL BURNER CONTROLS

PURPOSE:

To give the student an understanding of the importance of electric relays in the functions of circulators and fans used in Oil Burner Circuits.

EXPLANATIONS:

In the information sheet previously presented, you studied the function of the stack control with the thermostat, aquastat, and pyrostat. This explained the operations of only one of the simpler types of systems (the Hot Water System). There are 8 basic types of systems used today. These are:

1. Steam or Gravity Hot Water System
2. Steam Systems with Tank Type Domestic Hot Water Heater
3. Forced Circulation Hot Water System
4. Forced Circulation Hot Water System with Tank Type Domestic Hot Water Heater
5. Zone Control Forced Hot Water System with Tank Type Domestic Hot Water Heater
6. Forced Circulation Hot Water System with Tankless Domestic Hot Water Heater
7. Gravity Warm Air System
8. Forced Warm Air System

When studying systems other than the conventional Hot Water System, we are faced with additional electric circuits and controls. Example: (A) Circulative System in the Forced Circulation Hot Water Systems and Zone Hot Water Systems, (B) Fan Motors in the Forced Warm Air Systems.

CIRCULATORS

In the Forced Circulation and Zone Control Forced Hot Water Systems, the thermostat feels need for heat closing relay, circulator will operate from this relay only if water is sufficiently hot to warrant circulation If water is too cold, stack relay will operate starting oil burner. Circulator relay comes into operation when water is warm enough. Oil burner will run until thermostat is satisfied or boiler temperature reaches excessive high point, which will cause aquastat or immersion limit control to open relay in stack control stopping oil burner. Circulator may continue to operate until thermostat is satisfied.

If stack has cooled and returned contacts to starting position, circulator will not operate until water has reached desired setting, then it will function until desired temperature is reached.

A sequence is thus controlled from relays which function only when requirements are met.

This type of system prevents cold water circulation through the lines, allows hot water to be taken for use for other than heating purposes.

FANS

In the Forced Warm Air System the thermostat feels need for heat and operates relay in stack control. If the air is warm enough fan will operate until thermostat setting is reached. If air is not warm enough (Stack control is cool and returned to operating contact) oil burner will operate. When air temperature reaches predetermined setting, fan will operate (through relay) and circulate warm air until thermostat is satisfied.

In all types of oil burner systems, relays are used in conjunction with other relays and control devices to insure correct and safe sequence of operation.

1. Draw a schematic electrical diagram of a Forced Circulation Hot Water System.

2. Explain the functions of the various control devices and relays.

3. Draw a schematic electrical diagram of a Forced Warm Air System.

4. Explain the functions of the control devices and relays.

5. In your own words explain the importance of relays in the safe and proper function of oil burner controls.

REFERENCES:

Penn Manual, Installation and Service for Automatic Controls

Minneapolis Honeywell, Handbook for the Installer and Serviceman

Other Popular Oil Burner Company Manuals

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 7
Page 1 of 4

Commercial Applications of Electromagnets

TELEGRAPH

PURPOSE:

(a) To study the construction and operation of a telegraph sounder, relay, and key.

(b) To study the operation of a Single Morse Telegraph Circuit.

MATERIALS USED:

Two keys, two sounders, two relays, eight gravity cells, wire ground clamps.

SKETCH:

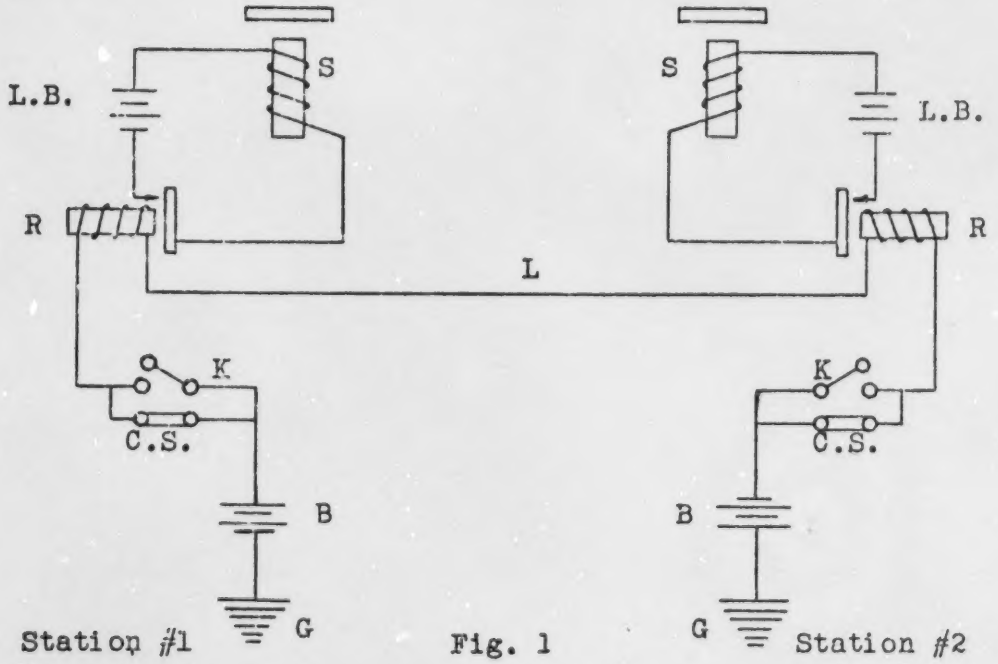


Fig. 1

Single Morse Circuit With Two Relay Stations

B - Main-line batteries
K - Keys
R - Relays
S - Local sounders
L.B. - Local batteries
L - Line
C.S. - Circuit-closing switches
G - Ground

PROCEDURE:

Connect up the apparatus so as to send and receive messages at two stations. Use a water pipe, a steam pipe, or other good ground for the return. In performing this experiment, it is well to locate station #1 and station #2 in different rooms.

The operator at station #1 will be called operator #1 and the operator at station #2 will be called operator #2.

Carefully examine the construction of the keys, relays, and sounder.

The diagram of connections shows the circuit of a single Morse telegraph between two stations using relays. When the line is idle, the circuit is kept closed by means of the circuit-closing switches associated with the keys as shown in the wiring diagram.

Telegraphic signals are made up of a combination of long and short current impulses which are made by pressing the sending key at proper intervals and for proper periods. The telegraph key is merely a quick-acting switch for opening and closing the circuit. Each combination of dots and dashes represents a letter of the alphabet or a certain word or phrase. To read signals from a sounder successfully, it is necessary to be able to distinguish between the clicks of the armature against the top and bottom stops. As current is allowed to pass through the magnet the armature is drawn against the bottom stop which causes a click, then, as the current is stopped the magnet releases the armature permitting it to spring back against the top stop. The difference in the time interval between bottom click and top click makes the difference between a dot and a dash (short interval = dot; long interval = dash). Then, the difference in time interval between top click and bottom click (note the reverse order) represents the spacing between dots and dashes. This spacing is made to vary (by keeping the key open) so that the operator may know whether it is a space between parts of a letter, parts of a word, or parts of a sentence.

The following schedule based on duration or length of time allowed for a dot will give the apprentice an idea of the time interval used.

The dash is equal to two dots.
The long dash is equal to four dots.
The space between the dots and dashes of a letter is equal to one dot.
The space between letters of a word is equal to two dots.
The space between words is equal to three dots.

PROCEDURE - (Continued)

Part I - Operator #1 Sends Message

(a) Operator #1 interrupts the circuit by opening switch C.S. at station #1. The switch C.S. at station #2 is left closed. Operator #2 is waiting to take down the message. Operator #1 makes and breaks the circuit by pressing his fingers on the key and releasing.

(b) Operator #1 presses the key. Both operators observe what takes place. Is the sounder armature against the top or bottom stop? Is the same true in both stations?

(c) Operator #1 releases the key. Both operators observe what takes place. Is the sounder armature against the top or bottom?

Both operators carefully observe what takes place in the sounders and relays under all conditions of operations. They should be able to tell exactly what happens when the circuit is made or broken. If any of the sounders or relays fail to operate, it may be necessary to adjust the set screws so as to bring the armature closer to the electromagnets.

(d) When Operator #1 finishes his message, he closes the switch C.S. at Station #1.

Part II - Operator #2 Sends Message

(a) Operator #2 proceeds to send a telegram. Operator #2 opens the switch C.S. at station #2. Operator #2 depresses the key. Both operators observe what happens. Operator #2 releases the key. Both operators observe what takes place.

(b) Repeat several times sending and receiving messages until you are able to distinguish between a dot, a dash, and a space.

(c) After finishing a message close the switch C.S.

QUESTIONS:

1. What are the essential parts of a Morse Single Line telegraph system?

2. Draw a diagram showing the paths of the current through the batteries, keys, relays and sounders.

QUESTIONS - (Continued)

3. Describe the construction and operation of:
   (a) Telegraph key
   (b) Telegraph relay
   (c) Telegraph sounder
   Include a sketch with each of the above descriptions.

4. What is the object of the relay? What is accomplished by the use of relays on telegraph lines.

5. What is the sounder used for? Why use both a relay and a sounder and a relay? What is the difference between a sounder and a relay?

6. On what does the operation of the relay depend?

7. Explain in detail the operation of the telegraph system used in this experiment.

8. What is the Morse Code? Are there any other codes in use?

9. Tell what Samuel F. B. Morse contributed to the commercial world.

10. What is a Telegraph Repeater?

11. May more than one telegraph communication be sent over a single wire?

12. Has hand transmission of telegraph signals been largely superceded by automatic methods? Which gives the greater speed?

REFERENCES:

Swoope's Lessons in Practical Electricity - Pages 600-612
5th Printing 1926

Basic Electricity - Marcus

Industrial Electricity - William H. Timbie

Electricity, Charles A. Rinde

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 8
Page 1 of 3

Electromagnetic Instruments

D'ARSONVAL MOVEMENT

PURPOSE:

To discover the underlying principle of direct-current instruments.

MATERIALS USED:

Horseshoe magnet, upright support, #30 insulated copper wire, #24 insulated copper wire, thread, dry cell.

SKETCH:

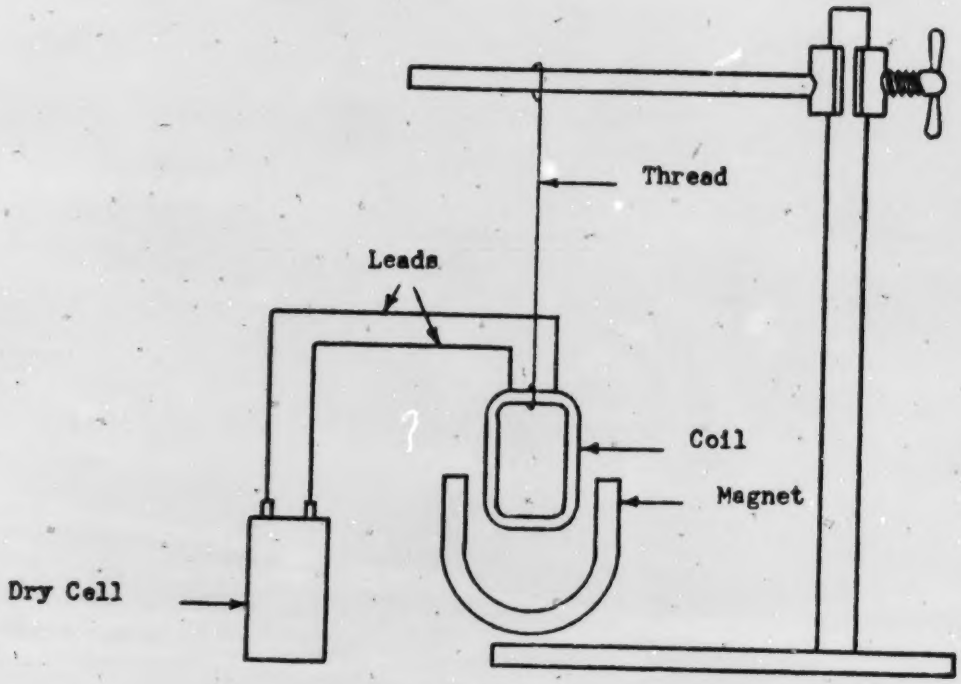


Fig. 1.

PROCEDURE:

Wind a coil of about 60 turns of #24 insulated copper wire (inside dimensions about 4" x 1 1/2"). Solder the leads (#30 insulated copper wire) to the coil. (The #30 wire is used to obtain leads of extra flexibility). Suspend this coil by a piece of thread between the poles of a horseshoe magnet. (Figure 1). Connect the leads to a dry cell.

PROCEDURE - (Continued)

(a) Note what happens to the coil with the current passing through it.

(b) Reverse the current flowing in the coil and note what happens.

QUESTIONS:

1. Explain in detail what you saw take place in this experiment.

2. What was the effect of reversing the current flowing in the coil?

3. Review:
   (a) What surrounds a coil carrying current?
   (b) Do the opposite faces of the coil shown in Figure 1 have the same or different poles when direct current is passing through it? Explain.
   (c) What always surrounds a magnet?
   (d) Is the north pole of the coil attracted or repelled by the south pole of the magnet?
   (e) Is the south pole of the coil attracted or repelled by the north pole of the magnet?

4. With the coil (Figure 1) free to turn what causes it to move when the current passes through it?

5. Does or does not the coil tend to move so that its own magnetic lines of force will be in the same direction as the lines of force of the magnetic field belonging to the magnet? Explain.

6. What fact have you discovered in this experiment?

   Important

   The apprentice must thoroughly understand the behavior of a coil carrying a current when placed in a magnetic field because it is the underlying principle of most instruments and in addition is the principle upon which all electric motors operate.

7. What is a galvanometer?

8. Explain the construction and operation of a D'Arsonval galvanometer.

9. (a) Upon what principle is the D'Arsonval galvanometer based?
   (b) Is or is not this galvanometer a commercial application of the fact you discovered in this experiment? Explain.

REFERENCES:

Swoope's Lessons in Practical Electricity

Basic Electricity, Marcus

Industrial Electricity, Nadon & Gelmino

Fundamentals of Electricity, Theodore Benjamin

Electricity and Electronics, Basic., Steinberg & Ford
4th Edition

DIRECT CURRENT AMMETER WITH D'ARSONVAL MOVEMENT

PURPOSE:

To study the construction and operation of an ammeter having a fixed permanent magnet and a movable coil.

PROCEDURE:

Carefully study the construction of a D. C. ammeter having a D'Arsonval movement. (Consult your instructor before beginning).

Note the following:

(a) Construction of the magnetic circuit of the instrument.
(b) How the soft iron cylindrical core is held between the pole pieces.
(c) Construction and assembly of the movable coil, springs and pointer.
(d) Whether very fine or coarse wire is used on the movable coil.
(e) Upon what the coil is wound.
(f) Are the coil and frame light in weight?
(g) In what the coil is pivoted.
(h) Where the coil is located relative to the soft iron core and permanent magnet.
(i) Number of spiral springs and two purposes these springs serve.
(j) Construction of shunt and connections relative to the movable coil.

QUESTIONS:

1. (a) Draw a sketch showing the essential parts of a D'Arsonval ammeter.
   (b) Explain its construction (in your write-up include "a to j" of the Procedure).
2. (a) What causes the coil to move when current is sent through it?
   (b) Explain how Experiment 1 illustrates the principle of operation of this instrument.

QUESTIONS (Continued)

3. The coil cannot safely carry a current greater than 0.025 ampere. (The moving coil of the Weston portable instrument deflects to full scale value with about 0.01 ampere in the coil). Therefore, in order to measure currents greater than 0.025 amperes, a shunt is used (Review Exp. D, Unit 2, Block XII). Draw a sketch showing how the coil is connected relative to the shunt.

4. Are the following statements true? "The current taken by the coil is almost negligible as compared with the main current. Therefore, in most cases, the line current practically equals the shunt current."

5. Which has the greater resistance, the shunt of a 10 ampere portable instrument or that of a 100 ampere portable instrument? (Same moving coil in each instrument).

6. Is the resistance of an ammeter very low or high?

7. Explain why an ammeter would be ruined if connected across the line.

8. Review: Explain how to connect an ammeter to a circuit. Include a sketch in your answer.

9. Review: List all precautions you must observe when using ammeters.

10. (a) Why is the instrument itself sometimes marked a millivoltmeter and used with an external shunt; while others are calibrated in amperes but still are used with an external shunt?

    (b) Explain how to measure the current in a circuit by using a shunt and a millivoltmeter.

11. What is
    (a) Millimeter
    (b) Micro-ammeter

12. When the aluminum frame, on which the coil is wound, is rotated in the magnetic field, momentary eddy currents flow around the frame in the opposite direction to the current in the coil. Explain how these momentary eddy currents tend to stop the motion of the coil and have the effect of preventing the needle from oscillating and thus making the instrument "dead-beat".

QUESTIONS (Continued)

13. Why is a mirror located on the scale card of portable instruments?

14. Are the divisions equally spaced on the scale?

REFERENCES:

Charts: Weston, General Electric Company

Swoope's Lessons in Practical Electricity - Page 236

Handbook for Electrical Metermen

Direct Current Fundamentals - Delmar

Electricity and Electronics, Basic. Steinberg & Ford
4th Edition

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 10
Page 1 of 1

Electromagnetic Instrument

DIRECT CURRENT VOLTMETER - D'ARSONVAL

PURPOSE:

To study the construction and operation of a direct current voltmeter.

PROCEDURE:

Carefully study the construction of a D. C. voltmeter having a D'Arsonval movement (Consult your instructor before beginning).

QUESTIONS:

1. Does the construction of a voltmeter differ materially from that of an ammeter insofar as the movement and magnet are concerned?

2. What is the principal difference between an ammeter and a voltmeter?

3. (a) Draw a sketch showing how to connect an ammeter to the circuit.
   (b) Draw a sketch showing how to connect a voltmeter to the circuit.

4. (a) Draw a sketch showing the essential parts of a D'Arsonval voltmeter.
   (b) Explain its construction and operation.

REFERENCES:

Charts: Weston, Jewel, etc.
Swoope's Lessons in Practical Electricity
Basic Electricity, Marcus
Industrial Electricity, Nordon & Gelmine
Fundamentals of Electricity, Theodore Benjamin
Direct Current Fundamentals - Delmar
Electricity & Electronics, Basic. - Steinberg & Ford.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 11 — Electromagnetic Instruments
Page 1 of 3

DYNAMOMETER MOVEMENT

PURPOSE:

To discover what happens when a current-carrying movable coil is placed within a fixed coil carrying current.

MATERIALS USED:

#30 insulated copper wire, supporting stand, thread, lamp bank, two 60 watt 115 volt incandescent lamps.

SKETCH:

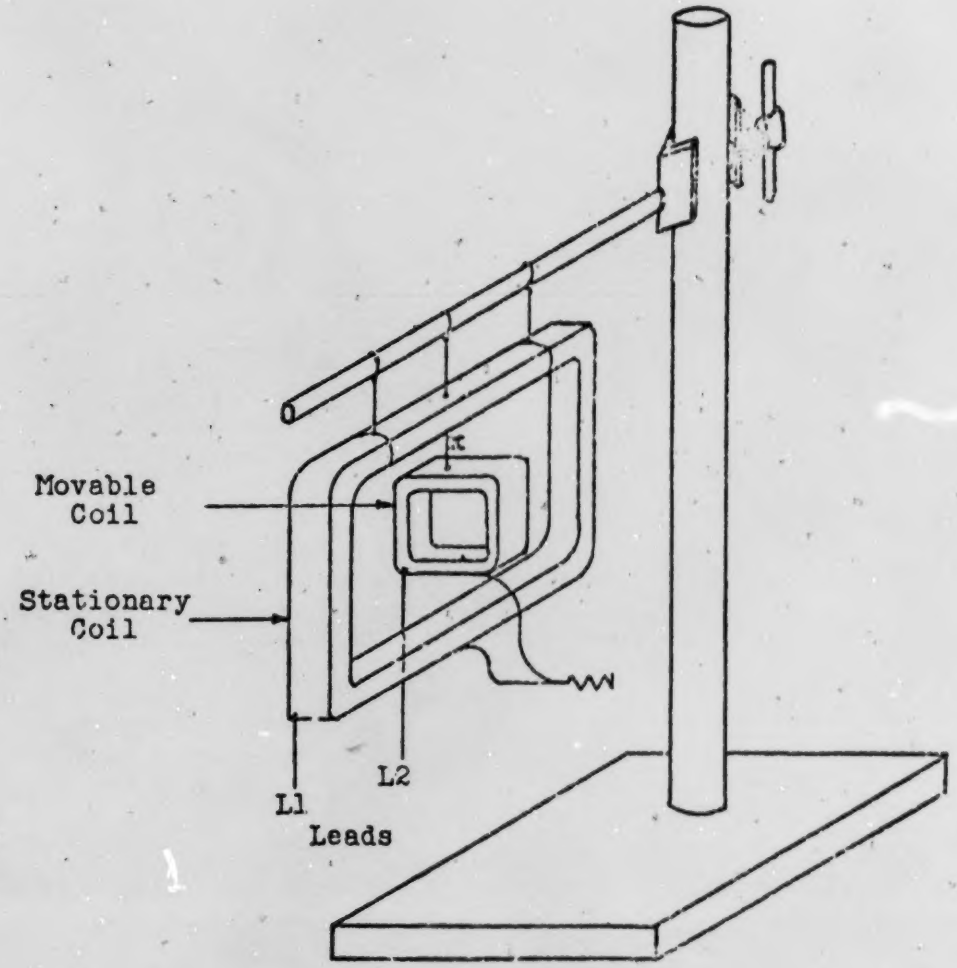


Fig. 1

PROCEDURE:

Part I:

Wind two coils each with 300 turns of #30 insulated copper wire. Have the inside dimensions of one coil 2" x 3 1/4" and the other 1 1/4" x 2".

Support the stationary coil with heavy cord as shown in Figure 1. Suspend the movable coil by a piece of thread. Spread the stationary coil apart so that the thread may easily pass through it at X. Connect the two coils in series as shown in Figure 1. Connect a lamp bank in series with the load L_1. With two 60 watt 115 volt lamps (incandescent) in the lamp bank apply 115 volts D.C. to the circuit. Note what happens. Reverse the current through the coils by interchanging the leads L_1 and L_2. Again note what happens.

Repeat the experiment using 115 volts alternating current.

QUESTIONS:

1. Describe fully everything you saw take place.
2. What causes the movable coil to turn?
3. How do you account for the fact that interchanging the leads L_1 and L_2 did not reverse the direction of motion of the movable coil, while so doing did reverse the direction of the motion of the movable coil in Exp. 8 of this unit?
4. What happened when alternating current was used?

PROCEDURE:

Part II:

Wind a third coil with 300 turns of #30 insulated copper wire (2" x 3 1/4"). Connect the apparatus as follows: Connect the two fixed coils (Figure 2) so that their magnetic fields act in conjunction. In other words these two fixed coils may be considered as being two parts of a single coil, separated at the middle to allow the thread attached to the movable coil to pass through. Connect this movable coil in series with the fixed coils. Place a thin fibre spacer between the fixed coils. Why?

Repeat the various tests listed under Part 1.

QUESTIONS:

5. (a) Explain in detail what you saw take place under Part II.
   (b) Compare the results with those of Part I.

QUESTIONS (Continued)

6. What fact have you discovered in this experiment?

7. (a) With the coil free to turn (Figure 1 and Figure 2), what causes it to move when current passes through it?

   (b) Compare your answer with that of Question 4 of Experiment 8 of this unit.

8. Does or does not the coil tend to move so that its own magnetic lines of force will be in the same direction as the lines of force of the magnetic field belonging to the stationary coils? Explain.

9. Compare the D'Arsonval movement and the dynamometer movement.

10. (a) Why can't the D'Arsonval movement be used on A.C. circuits?

    (b) Can the dynamometer movement be used on either A.C. or D.C.? Why?

REFERENCES:

Basic Electricity - Marcus

Swoope's Lessons in Practical Electricity, E. Hausmann

SKETCH:

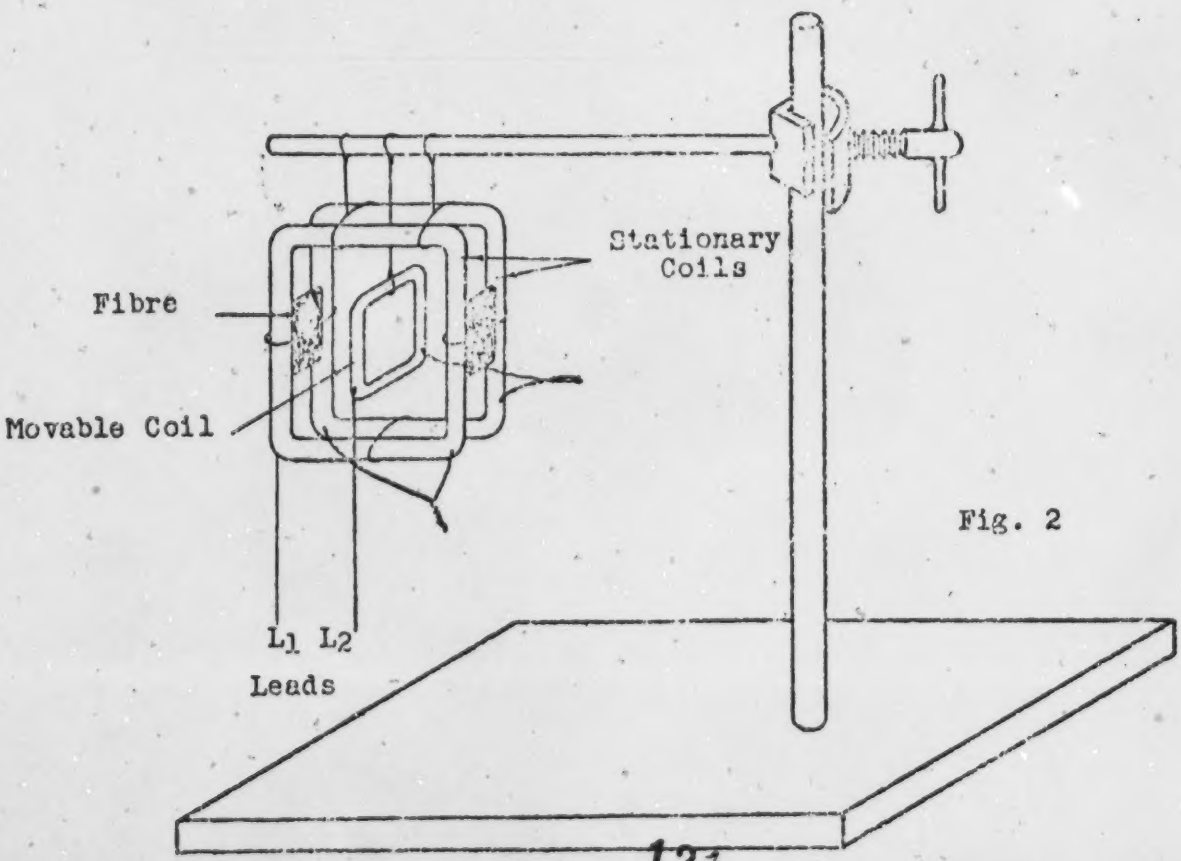


Fig. 2

Experiment No. 12
Page 1 of 2

Electromagnetic Instruments

THE ELECTRO-DYNAMOMETER VOLTMETER

PURPOSE:

To study the construction and operation of an A.C. voltmeter of the dynamometer type.

PROCEDURE:

Carefully study the construction of an A.C. voltmeter having a dynamometer movement (Consult your instructor before beginning).

QUESTIONS:

1. Draw a sketch showing the essential parts of an A.C. voltmeter of the dynamometer type.
2. Explain the construction and operation of this voltmeter.
3. Explain how Experiment 11 illustrates the principle of this instrument.
4. Is the scale divided uniformly like that of the direct-current voltmeter?
5. Can the divisions at the lower part of the scale be read with a high degree of accuracy?
6. Is this instrument damped?

EXPLANATORY NOTES:

The dynamometer type of voltmeter takes about five times as much current as a direct-current voltmeter of the same rating. The moving coil operates in a comparatively weak field and is very susceptible to stray fields.

QEUSTIONS (Continued)

7. (a) How is an instrument shielded?
   (b) Why is it shielded?

QUESTIONS (Continued)

8. May the dynamometer type of instrument be used on D.C. circuits?

9. Is it possible to tell the polarity of a D.C. circuit by use of an electro-dynamometer type instrument?

10. Is there any iron in the electro-dynamometer movement?

REFERENCES:

Charts: Weston, General Electric Company
Handbook for Electrical Metermen
Electrical Measurement - Delmar; Page 72 - 1947
Basic Electricity - Marcus
Industrial Electricity - Nadon & Gelmine

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 13
Page 1 of 2

Electromagnetic Instruments

WATTMETER

PURPOSE:

To study the construction and operation of a wattmeter.

PROCEDURE:

Carefully study the construction of a wattmeter. Consult your instructor before beginning.

QUESTIONS:

1. On what principle does the wattmeter operate?
2. (a) Is the movable coil wound with fine or coarse wire?
   (b) Is it in any way similar to the moving coil of the dynamometer voltmeter? Explain.
   (c) What is in series with it?
   (d) How is the current led into this coil?
3. (a) How many fixed coils are there?
   (b) Are there many or few turns? Why?
   (c) Is the wire coarse or fine? Why?
4. What is the potential circuit of a wattmeter?
5. What is the current circuit of a wattmeter?
6. (a) Draw a sketch showing the essential parts of a wattmeter.
   (b) In this sketch show the connections of a wattmeter in an electrical circuit.
7. Explain the construction and operation of a wattmeter.
8. Make a list of all the precautions you must observe in using wattmeters.
9. How are you able to distinguish the potential terminals from the current posts on a wattmeter?

QUESTIONS (Continued)

10. In a wattmeter
    (a) What corresponds to the voltmeter?
    (b) What corresponds to the ammeter?

REFERENCES:

Swoope's Lessons in Practical Electricity, E. Hausmann
Basic Electricity, Marcus
Direct Current Fundamentals, Delmar

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 14
Page 1 of 3

Electromagnetic Instruments

IRON VANE MOVEMENT

PURPOSE:

To discover the underlying principle of iron vane instruments.

MATERIALS USED:

Two pieces of annealed steel (2 7/8" x 3/16" x 3/4"), #18 insulated copper wire, three 100 watt lamps, thread, compass.

SKETCH:

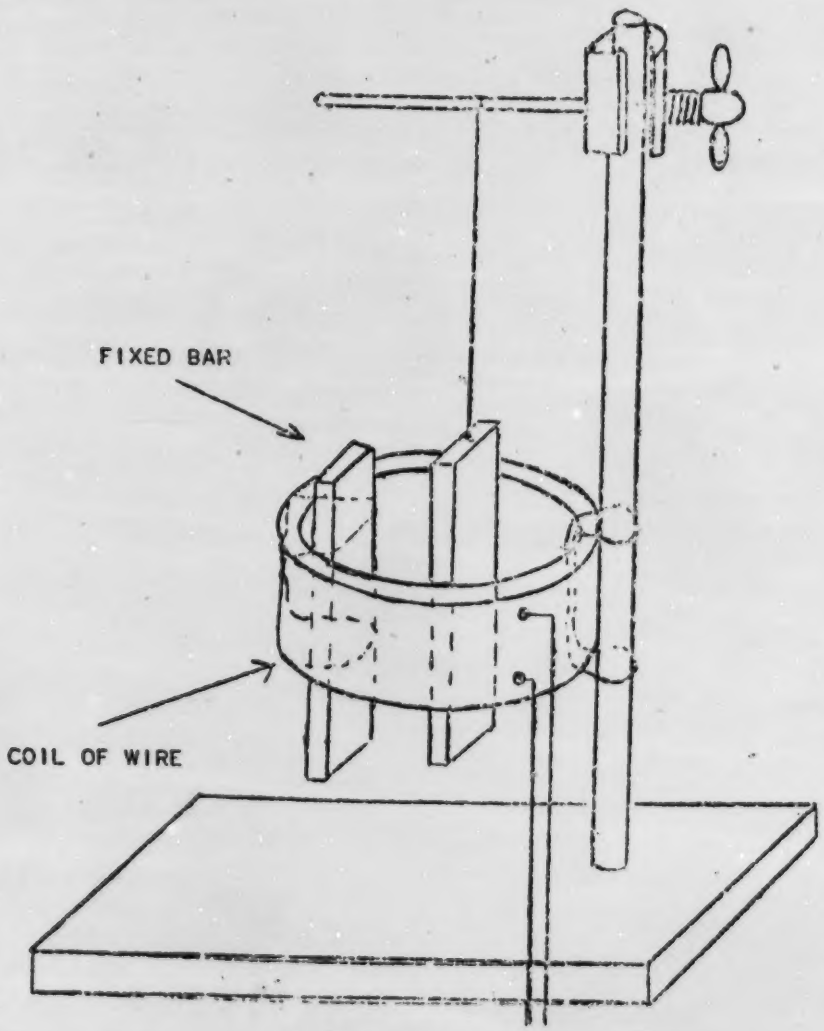


Fig. 1

PROCEDURE:

Wind a coil of about 200 turns of #18 insulated copper wire, (3" diameter, 2" high, 1/2" thick).

Drill a small hole at one end of each steel bar. Tie a piece of thread to each bar.

1. By means of threads vertically suspend the two pieces of soft iron at the center of the coil. With no current flowing through the coil, note what happens. Draw a sketch.

2. Connect the lamp bank in series with the coil. With three 100 watt lamps in the circuit, pass direct current through the coil. Note what happens. Test the polarity of each bar. Draw a sketch showing what happens when current passes through the coil. Indicate the polarity of each bar.

3. Reverse the current. Note what happens. Test the polarity of each bar. Draw a sketch showing what happens. Indicate the polarity of each bar.

4. Pass alternating current through the coil and note what happens. Draw a sketch.

5. Fasten one of the bars so that it cannot move. (Figure 1). Suspend the other bar close to it. Have it free to move. With no current flowing through the coil, note what happens. Draw a sketch.

6. Pass direct current through the coil. Note what happens. Draw a sketch.

7. Pass alternating current through the coil. Note what happens. Draw a sketch.

8. Repeat, using one 100 watt almp, two 100 watt lamps, three 100 watt lamps respectively.

QUESTIONS:

1. Review: What happens when an unmagnetized piece of steel is suspended vertically in a coil carrying direct current?

2. Review: What is the law concerning the attraction and repulsion of magnets?

3. Review: Does soft iron retain its magnetism after the current is removed?

QUESTIONS (Continued)

4. Review: What effect has reversing the current in the coil upon the polarity of the magnet?

5. Did reversing the polarity of the coil affect the motion of the bars? Explain.

6. If the movable bar is so attached that it can only move by rotating, would it always tend to rotate in the same direction regardless of the direction of the current in the coil. Explain.

7. Compare the results of passing direct current through the coil with those when alternating current was passed through the coil.

8. What caused the bars to move in this experiment?

9. What fact have you discovered in this experiment?

10. (a) Could this principle be used to make a voltmeter or an ammeter?

    (b) If so, could it be used on either direct or alternating current? Explain.

REFERENCES:

Weston - Monograph B-7

Basic Electricity - Marcus

Electricity - Charles A. Rinde

Experiment No. 15
Page 1 of 2 Electromagnetic Instruments

IRON VANE MOVEMENT

PURPOSE:

To study the construction and operation of an iron vane type of instrument.

PROCEDURE:

Carefully study the construction of a Weston iron vane ammeter. (Consult your instructor before starting).

NOTES:

Ammeters of the dynamometer type are not common because of the difficulty of leading a heavy current into the moving coil. It is not practical to use a shunt as in the case of the D'Arsonval type of D.C. ammeter because, unless the ratio of inductance to resistance were the same in the shunt as in the moving coil, the instrument would be correct at only one frequency. Why? Although instruments of the dynamometer type, in which these difficulties are partly overcome, are available, the iron vane type of instrument is so simple and less expensive that the dynamometer is little used as an ammeter.

QUESTIONS:

1. (a) Explain the construction of the movable vane.
   (b) Explain the construction of the fixed vane.
2. Draw a sketch showing the essential parts of an A.C. ammeter of the iron vane type.
3. Draw a sketch showing the essential parts of an A.C. voltmeter of the iron vane type.
4. What is the essential difference between an A.C. voltmeter of the iron vane type and an A.C. ammeter of the iron vane type?
5. Explain in detail the operation of an iron vane instrument, That is, tell what causes the needle to move when current passes through the coil.
6. Can this type of instrument be used on D.C. circuits?

QUESTIONS (Continued)

7. Could you tell the polarity of a D.C. circuit by use of an iron vane type instrument? Explain

8. Is there any current led into the moving element in this instrument?

9. How is damping obtained in:
   (a) A.C. instruments of the electro-dynamometer type?
   (b) A.C. instruments of the iron vane type?

10. Is the scale of the iron vane instrument divided uniformly like that of the D'Arsonval type instrument?

11. With what three types of instruments are you familiar?

12. Why is the dynamometer principle well adapted to voltmeter construction but not to ammeters?

13. Why are most A.C. voltmeters of the dynamometer type, while most A.C. ammeters are of the iron vane type?

14. Which has the greater accuracy, an iron vane voltmeter or a voltmeter of the dynamometer type? (Consult manufacturers' catalogues).

15. You have found that an iron vane instrument or an instrument of the dynamometer type may be used on either D.C. or A.C. Why, then, dowe have D.C. instruments of the D'Arsonval type which can only be used on D.C. circuits? Hint: Consult manufacturers' catalogues.

REFERENCES:

Charts: Weston, Jewel, etc,
Weston - Monograph B-7 - Pages 40-43
Electricity, Charles A. Rinde
Basic Electricity, Marcus
Direct Current Fundamentals - Delmar

COMMERCIAL APPLICATIONS OF ELECTROMAGNETS - REVIEW

In the series of information sheets and experiments you have discovered many commercial applications for electromagnets. However, only a very few of the many uses of electromagnets have been touched upon. Therefore, the apprentice should constantly be on the alert to recognize the part played by electromagnets in the operation of electrical apparatus.

One of the most important uses of electromagnets is in the magnetic fields of motors and generators. As you will discover in the next lessons, they are used to produce the strong magnetic fields necessary for the development of large quantities of electrical power.

QUESTION:

1. Make a list of all the commercial applications for electromagnets with which you are familiar.

SINGLE PHASE ALTERNATING CURRENT GENERATOR

PURPOSE:

To study the construction and operation of a commercial single phase A.C. Generator, its parts, and their functions.

APPARATUS NEEDED:

Commercial single phase A.C. Generator

REVIEW QUESTIONS:

1. What is an electric generator?
2. On the fundamental principle of a generator
   (a) What happens when a wire is moved across a magnetic field so that it cuts magnetic lines of force?
   (b) What happens when, with the wire stationary, the magnetic field is moved?
   (c) What three factors determine the e.m.f. induced in the conductor?
   (d) Explain the fundamental principle of a generator.
   (e) Using a horseshoe magnet, a piece of wire, and a galvanometer, explain how you could demonstrate the principle of an electric generator. Include a sketch in your answer.
   (f) Referring to parts d and e, is it necessary that the wire cut the lines of force? In other words, if the wire were moved parallel to the lines of force, would there be any e.m.f. produced?
   (g) What determines the direction of the current flowing in the wire?
   (h) Explain the fundamental principle on which all generators work.
3. Why is it necessary that a generator be driven by a steam turbine, water wheel, gasoline engine or other mechanical force?
4. Does a generator create electricity or rather does it convert merchanical energy into electrical energy? Explain.
5. As more load is placed on a generator, must more mechanical energy be supplied? Explain.

REVIEW QUESTIONS (Continued)

6. Draw a sketch of the simple generator.

7. Suppose you replaced the horseshoe magnet by two electromagnets, in the model generator you built. Would an e.m.f. still be produced when the coil is rotated? Explain in detail.

8. Suppose you had several coils, connected in series, on the armature of your model generator, and the beginning of this winding was connected to one collector ring and the ending of the winding to the other collector ring. What would be the effect upon the induced e.m.f.?

EXPLANATORY NOTES: The Alternating Current Generator

A study of the model generator reveals the following fact: a generator consists essentially of two parts, (a) a magnetic field produced by a magnet or an electromagnet, (b) an armature, which in a commercial generator, consists of a number of loops or coils of wire placed in the slots of an iron core.

In the magneto you found that several horseshoe magnets placed side by side, produce the magnetic field. However, in the commercial generator, electromagnets are used because they will produce a much stronger field. A generator having one N-pole and one S-pole in its field is called a bi-polar generator. A generator having more than two poles is called a multipolar generator.

In the model generator you found that in order to use the current generated in the coil when it was rotated in the magnetic field, some mechanical device was needed to lead the current from the rotating coil to the external circuit.

To accomplish this two collector rings (which rotated with the shaft) were used. The ends of the loop were connected one to each ring, (the rings being insulated from each other and the shaft). Stationary contacts called brushes rested against the collector rings and lead the current to the external circuit. In the commercial generator the brushes are usually made of carbon, although copper brushes are sometimes used.

A generator which delivers an alternating current is said to be an A.C. generator or, more often, is called an alternator. An A.C. generator with only one winding (several coils in series) is called a single phase generator. Although the single phase generator is little used, we will study its construction and operation so as to be better able to understand

EXPLANATORY NOTES (Continued)

The direct current generator. The single phase generator is much heavier and much more expensive than the three-phase machine of the same capacity.

You have discovered that the generation of an e.m.f. in a conductor may take place with the magnetic field stationary and the conductor moving, or with the conductor stationary and the field moving past the conductor. In other words, it is merely necessary that there be relative motion between the conductor and the field. Hence generators may be divided into three classes as follows:

1. Those having a stationary armature and a revolving field.
2. Those having a stationary field and a revolving armature.
3. Inductor alternators - These have a stationary armature and a stationary field. The variation in the flux through the armature winding is produced by the rotation of the iron inductors. This alternator has no moving wire or contacts. (See Swoope's Lessons in Practical Electricity, Page 540).

Modern alternators with few exceptions belong to the first class (revolving field type) because the high voltage or large currents produced in the armature do not have to be led through collector rings. On the other hand, the field voltage is never over 230 volts and the current is not large. The difficulties in the design of inductor alternators has caused this type of alternator to become almost obsolete except for special cases. It has been used as a high frequency alternator for some radio-telegraphic systems. A few 5,000 cycle generators of the inductor type have been built during the past few years for high frequency induction furnaces. (The conventional type of electromagnetic generator is not considered suitable for frequencies higher than 2,000 cycles per second). This high-frequency generator still remains relatively costly and inefficient when compared to our modern 60 cycle alternators; but, with the increasing use of high-frequency induction furnaces, the need for development of efficient generators for such applications becomes apparent. However, the total furnace demand for 5,000 cycle power will probably be so small and its transmission is so difficult that it will probably never be generated in central stations. The industrial plant will probably produce its own, by means of motor-generator sets, etc.

In A.C. generators having a stationary field and a revolving armature the current is conducted from the armature by collector rings. A single phase generator has two collector rings.

In A.C. generators the stationary member is called the stator, and the rotating member is called the rotor.

EXPLANATORY NOTES (Continued)

In A.C. generators having a stationary armature and a revolving field, the current is led into the field by the collector rings.

In order to provide a uniform magnetic field direct current must be supplied to the field. Usually the field current is furnished by an auxiliary small generator called an exciter. The exciter may be driven by a separate prime mover, or, the exciter may be directly connected (mounted on an extension of the main generator shaft.)

(See Swoope's, Page 419). In a few small alternators of the revolving armature type, the field excitation is supplied by a separate direct current winding on the armature. The armature in addition to having an alternating current winding has a separate direct current winding connected to a commutator (see Swoop's, Page 536). Such an alternator is self-exciting. This method, except for small machines, is little used.

REVIEW QUESTIONS (Continued)

9. Why isn't alternating current used to excite the fields of an alternator?

10. What is an exciter?

11. (a) Why do A.C. generators require an exciter?
(b) Describe different methods for obtaining the excitation of an alternator.

12. Explain why the frequency of an alternator equals

$$\frac{\text{Number of poles}}{2} \times \frac{\text{Speed in revolutions per minute}}{60}$$

or rewritten $f = \frac{PS}{120}$

Where f is the frequency, in cycles per second
p is the number of poles
s is the speed in revolutions per minute

13. A 60 cycle turbo-alternator is driven at a speed of 3600 r.p.m. How many poles has it?

14. A water wheel drives a certain alternator at a speed of 120 r.p.m. If the alternator has 60 poles, what is the frequency?

15. At what speed must a four pole alternator be driven to develop 60 cycles?

REVIEW QUESTIONS (Continued)

16. If the frequency of an alternator drops to 59.5 cycles, how may it be brought back to 60 cycles?

17. (a) The field circuit of all generators, except possibly those of small size, must not be suddenly opened while carrying current. Why?
    (b) What kind of a switch is used?
    (c) What purpose does the "field discharge resistance" serve?

18. Are single phase A.C. generators used much? If not, why?

19. (a) Carefully study the construction and operation of a commercial single phase A.C. generator.
    (b) Make a written report.
    (c) Name all parts and tell their functions.
    (d) Make a wiring diagram of the machine.

20. What is the purpose of the collector rings?

21. Why are the collector rings insulated from each other and from the shaft?

22. What is the purpose of the brushes?

23. What is the brush holder? What purpose does it serve?

24. Why is the armature core built up of laminations?

25. Explain the construction of the bearing.

26. How are the bearings lubricated?

27. How is the voltage of an alternator controlled?

28. What advantage has an alternator with a stationary armature and revolving field?

29. What part do D.C. electromagnets play in A.C. generators?

REFERENCES:

Swoope's Lessons in Practical Electricity, E. Hausmann
American Electricians' Handbook
Elements of Electricity, William H. Timbie
Industrial Electricity, William H. Timbie
Basic Electricity, Marcus

Commercial Generators

DIRECT CURRENT GENERATOR

PURPOSE:

To study the construction and operation of a direct current generator.

MATERIALS USED:

Model generator, short piece of 1/2" copper tubing, galvanometer.

SKETCH

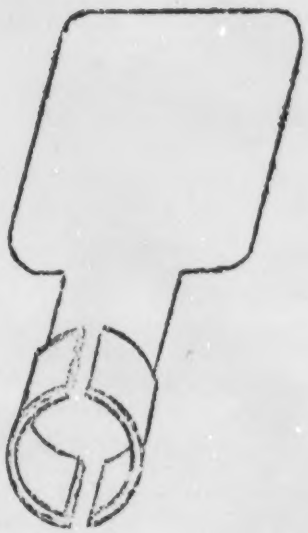


Fig. 1

PROCEDURE:

Build a model direct current generator in accordance with the following instructions:

Connect the two ends of the coil one to each of the sections (segments) (See Figure 1). Mount this split ring upon a hub insulated from the shaft. Insulate the segments from each other. This device is called a commutator. In its simplest form a commutator consists of copper ring split lengthwise into equal parts, mounted upon a hub insulated from the shaft, by mica or a similar material, with the segments also insulated from each other.

PROCEDURE (Continued)

Have the brushes rest upon the commutator at diametrically opposite points. Locate the brushes (Figure 3) so that when the coil is perpendicular to the magnetic field, the slits in the ring come in contact with the brushes. With the galvanometer connected across the brushes slowly rotate the shaft. Note the galvanometer deflection.

Reverse the direction of rotation and note the galvanometer deflection.

Reverse the polarity of the field, again rotate the coil and note the galvanometer deflection.

QUESTIONS:

1. (a) Is the reading of the galvanometer the same with the coil at different positions? If not, why?
   (b) Does it reverse?

2. Compare the action of the galvanometer when connected across the brushes of the model A.C. generator to that when connected across the brushes of the model D.C. generator you have just built. (The armature being rotated in each case.)

3. Is the current produced in the armature of a D.C. generator, alternating or direct? Prove your answer.

4. Is the current, delivered to the external circuit from this generator, alternating or direct current? Prove your answer by recalling the readings of your galvanometer as the coil was rotated.

EXPLANATORY NOTES - How The Commutator Changes A.C. to D.C.

If a direct current (one whose direction is always the same) is desired, it is evident that collector rings cannot be used. To have direct current, the current must always flow into the external circuit in the same direction. The machine which produces such a current is called a direct current (D.C.) generator.

In the model A.C. generator you built, you found that an alternating e.m.f. was induced in the rotating coil.

In the model D.C. generator you built, you had exactly the same coil for the armature and used exactly the same field. Hence the e.m.f. produced in the coil on this armature is alternating (just as in A.C. generator). The coil current in the armature of the D.C. generator is alternating because it is produced by an alternating e.m.f. Therefore, to have

EXPLANATORY NOTES (Continued)

direct current in the external circuit, this induced alternating current in the armature coils must be rectified before it reaches the external circuit.

You have discovered several ways of rectifying alternating current. One of these rectifiers was a mechanical rectifier (vibrating type). Although not discussed in that Block (because of its limited use), there is another mechanical rectifier known as the Commutating-Type Rectifier. (See Standard Handbook - 5th Edition - Section 6 - Paragraph 299; also Dawes - Electrical Engineering - Volume 2 - Page 334).

In the D.C. generator rectification is accomplished by an automatic switching device called a commutator. The commutator is a form of reversing switch placed between the armature and the external circuit so arranged that it keeps the current in the external circuit flowing in the same direction continuously, even though the current in the armature coil is periodically reversing.

The following detailed description should make clear to you how the alternating current of the armature is converted into direct current.

The commutator rotates with the shaft while the brushes which rest against the commutator are stationary.

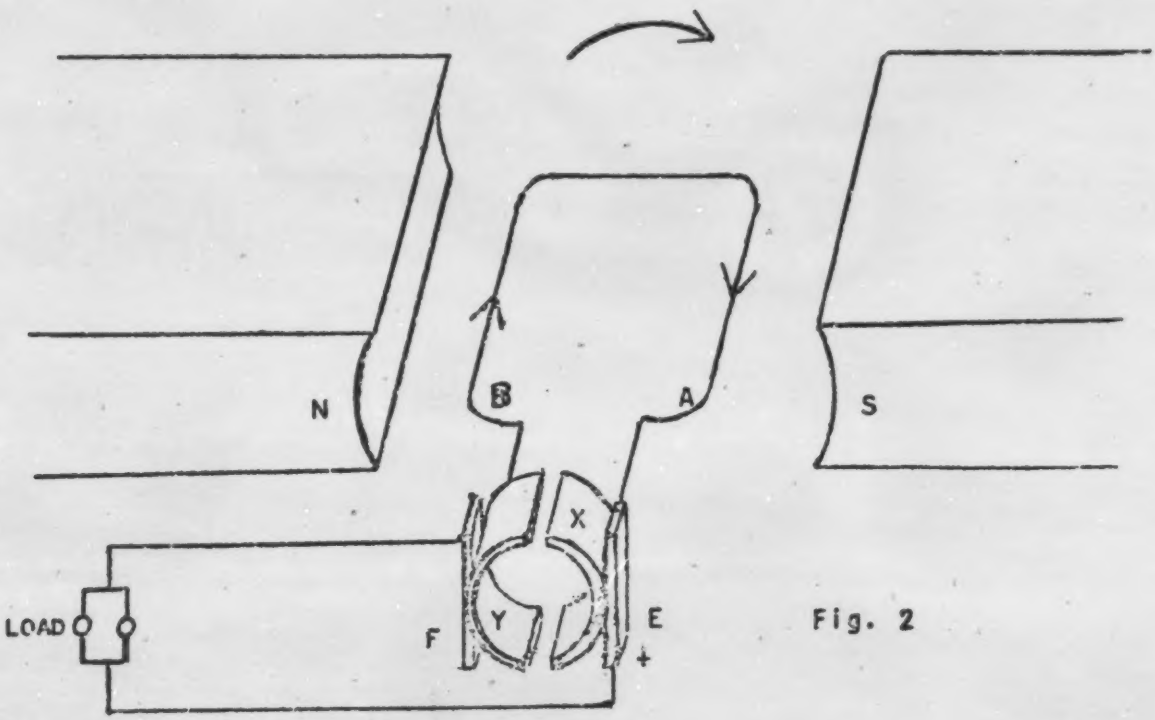


Fig. 2

EXPLANATORY NOTES (Continued)

When a wire was moved down between the poles of the horseshoe magnet, the induced current was opposite in direction to that induced when the wire was moved up between the poles of the horseshoe magnet. When a coil is rotated between a north and a south pole as shown in Figure 2, one side of the coil is moving down between the poles and the other side of the coil is moving up between the poles. This will cause the current flowing in one side of the coil to be opposite in direction to the current flowing in the other side of the coil. This is shown by the arrows in Figure 2 and Figure 4.

Figure 2, 3, and 4 show the coil of the model D.C. generator you built, at three different positions as it is rotated between the poles of the magnet (the coil is rotated in a clockwise direction facing the commutator end). With the coil in the position shown in Figure 2, the current flowing in side "A" of the coil is flowing out of the paper, while in side "B" of the coil the current is flowing into the paper. (Check this statement by applying Fleming's Right Hand Rule). With the coil in this position, brush "E" is rubbing on commutator segment "X" and brush "F" is rubbing on commutator segment "Y". With the coil in this position, the current flows from the side "A" of the coil into the commutator segment "X", through the brush "E", through the external circuit, into the brush "F", into the commutator segment "Y", into the side "B" of the coil.

The brush "E" where the current leaves the generator is called the positive brush. The brush "F" where the current re-enters the generator is called the negative brush. As stated above, the commutator is rigidly attached to the shaft and rotates with the shaft. The brushes are stationary and make contact with the commutator as it is rotated. As the coil in Figure 2 is rotated in a clockwise direction, the commutator segment "X" continues to make contact with the brush "E" (and the commutator segment "Y" makes contact with the brush "F") until the coil is in a vertical position as shown in Figure 3.

With the coil in the vertical position shown in Figure 3, the brushes are resting on the two slits of the commutator. Hence, brush "E" is in contact with both segment "X" and segment "Y". Also brush "F" is in contact with both segment "X" and segment "Y". This short circuits the coil. However, this does not do any harm because, with the coil in the vertical position it is moving parallel to the magnetic lines of force and no current flows in the coil.

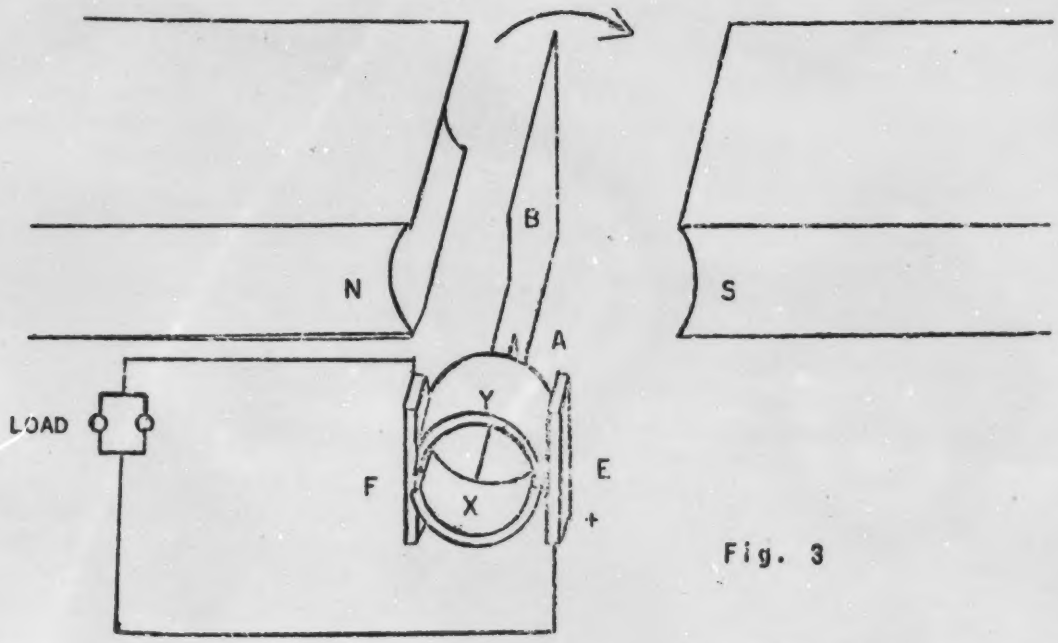


Fig. 3

(You will find that no e.m.f. is induced in a conductor when moved parallel to the magnetic lines of force.) Just as the coil passes the vertical position the commutator segment "X" leaves the brush "E" and is only in contact with brush "F". (Study Figure 3 and Figure 4).

At the same time segment "Y" leaves brush "F" and is making contact with brush "E" only, and the current reverses in side "B" of the coil because it is now moving down between the poles where before it was moving up. At the same time the current reverses in side "A" of the coil because it is now moving up between the poles. The arrows in Figure 4 show the direction of the current. Therefore, with the coil in the position shown in Figure 4, the current flows from the side "B" of the coil through the commutator segment "Y" (but commutator segment "Y" is now in contact with brush "E" where before it was in contact with brush "F"), through the brush "E", through the external circuit, into the brush "F", into the commutator segment "X", into the side "A" of the coil.

Comparing the direction of flow of the current in Figure 2 and Figure 4, it will be seen that the current is reversed in the coil within the generator; but that the current still flows in the same direction in the circuit outside the generator. The current still leaves the generator at the positive brush "E" and re-enters the generator at the negative brush "F". As pointed out above, the reason for this is that when the current in the coil is reversed, its connections to the

EXPLANATORY NOTES (Continued)

external circuit are reversed at the same time. Hence the current flows continuously in the same direction in the external circuit.

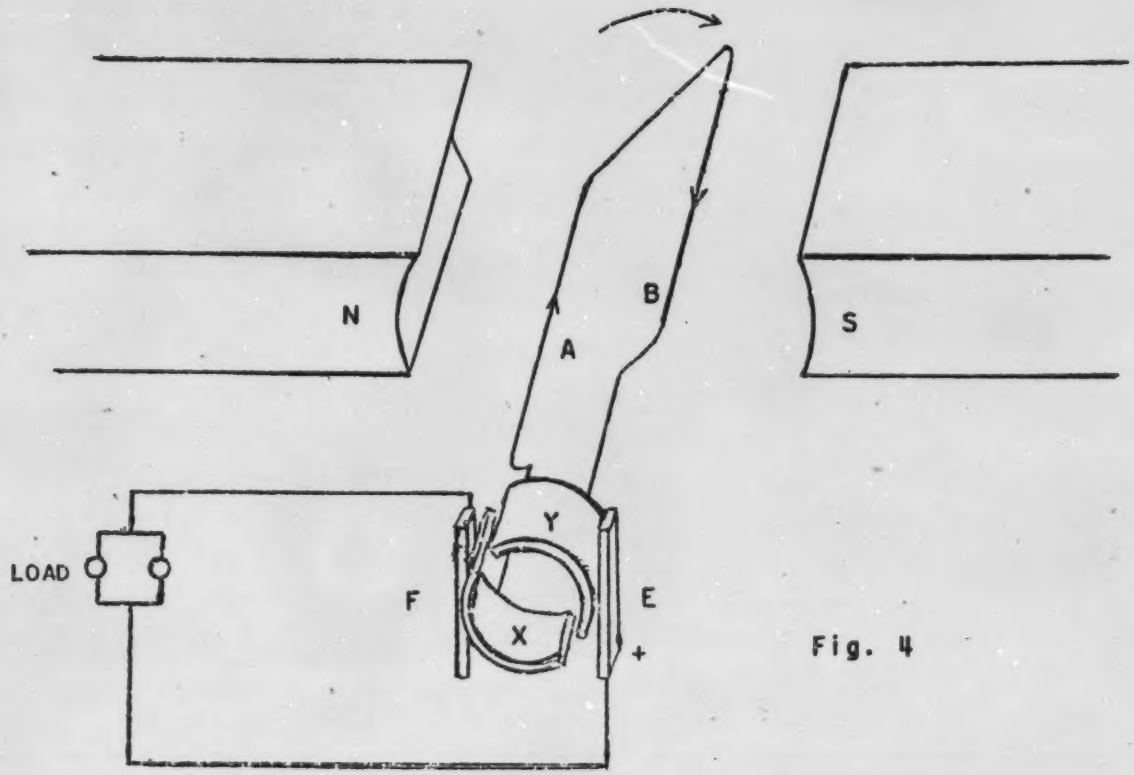
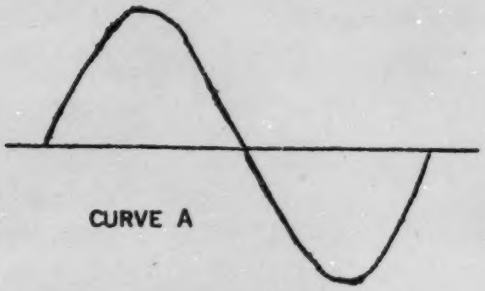


Fig. 4

From the above it is easy to see that a D.C. generator is an A.C. generator with an Automatic Reversing Switch.

Alternating Current
(A.C. Generator)

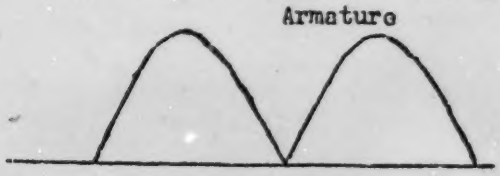


CURVE A

CURVE C

Continuous Current
(Battery)

Pulsating Current
D.C. Generator with one coil on Armature



CURVE B

CURVE D

Continuous Current (Slightly Rippled) Produced by a Commercial D. C. Generator

Curve (B) shows the rectified current of the model D.C. generator studied. This current varies from zero to a maximum but does not reverse. However, such a voltage could not be used commercially for direct current service. This voltage Curve (B) is improved by having a large number of coils on the armature. The commutators on commercial D.C. generators have a large number of commutator segments (one for each coil). By having a large number of coils a more constant e.m.f. (Curve D) is made possible at the terminals of the machine. Thus, there will always be at least one coil producing its maximum e.m.f., while others are going through zero or some intermediate value. The voltage at the terminals at any instant is equal to the sum of the voltages of the individual coils at that instant. This gives a fairly smooth voltage Curve (D).

QUESTIONS (Continued)

5. (a) Draw a sketch of the simple direct current generator you built in this experiment. Label all parts.
   (b) Explain the use of each part.

6. (a) What is a commutator?
   (b) What purpose does it serve in a direct current generator?

7. Explain the construction of a commutator.

QUESTIONS (Continued)

8. (a) Draw a sketch of an armature coil (rotating between two mganets) connected to two collector rings. Show the brushes resting against the collector rings.
   (b) Explain why alternating current is delivered to the external circuit.

9. (a) Draw a sketch of the same armature coil connected to a commutator. Show the brushes resting on the commutator.
   (b) Explain in detail why direct current is delivered to the external circuit. In other words, explain in detail how a commutator changes alternating current to direct current.

10. What are the three essential parts of a direct current generator?

11. (a) In what ways are single phase A.C. generators and D.C. generators similar (in construction and operation)?
    (b) What is the essential difference between them (in construction and operation)?

12. (a) What is a pulsating current?
    (b) What is a continuous current?
    (c) How is the so-called continuous current of the D.C. generator produced?

13. (a) How does the direct current generator voltage differ from the voltage of a primary battery?
    (b) How do they differ in regard to the method of generating electricity?

14. At what position must the brushes be placed on a commutator? Why?

15. Why has a commercial D.C. generator a large number of coils so arranged that one after another cuts the flux? Why has a commutator many bars instead of one coil only and a two-part commutator?

16. Why is knowledge of alternating currents needed in studying the operation of D.C. generators?

17. What part do electromagnets play in D.C. generators?

18. (a) What is the frame or yoke of a dynamo?
    (b) What two purposes does it serve?
    (c) What is it made of? Why?

QUESTIONS (Continued)

19. What is the field core of a dynamo? What is it made of?

20. What is the armature core made of?

21. Why are collector rings used on an alternating generator while a commutator is used on a direct current generator?

REFERENCES:

Basic Electricity, Marcus

Elements of Electricity, William H. Timbie

Fundamentals of Direct Current, Delmar

American Electricians' Handbook

DIRECT CURRENT GENERATORS
COMMUTATING POLES

PURPOSE:

To gain an understanding of how commutating poles compensate for armature reaction and the electromotive force of self-induction, and thereby produce sparkless commutations at all loads from no load to full load without shifting the brushes.

INFORMATION:

It is obvious that it would be more or less of a nuisance to shift the brushes on a generator every time the load changes. Of even greater importance is the fact that a very slight movement of the brushes in either direction causes a marked change in the flux. This makes good commutation difficult. (This is one of the reasons why the proper brush must be used on each generator). There have been various methods proposed (and tried out) for obtaining sparkless commutation at all loads, from no load to full load, without advancing or retarding the brushes. Some only decrease the sparking while others completely eliminate it.

Armature Reaction and the e.m.f. of Self-Induction are the two reasons why the brushes must be shifted as load is applied. Armature reaction causes an appreciable flux to exist in the geometrical neutral (no load neutral plane) when load is applied to the machine. It is obvious that if the flux (which we will call $\varnothing 1$), equal in value but opposite in direction to this flux, could be produced in the geometric neutral, the flux in this plane could be brought to zero in spite of armature reaction.

This would neutralize the flux in the neutral zone and thereby eliminate the sparking due to armature reaction. But we still have the e.m.f. of self-induction to contend with. It is obvious that, if we could produce a flux (call it $\varnothing 2$) in the geometrical neutral, of proper strength and direction to induce an e.m.f. equal and opposite to the e.m.f. of self-induction in the coil undergoing commutation, sparking due to self-induction would be eliminated.

From the above, it is evident that if we could produce in the geometrical neutral a flux equal to $\varnothing_1$ (to neutralize armature reaction) plus $\varnothing_2$ (to produce an e.m.f. to balance the e.m.f. of self-induction) that we could obtain <u>sparkless commutation</u> at <u>all loads without shifting</u> the brushes. Such a flux can be produced by placing narrow auxiliary poles, called COMMUTATING POLES, between the main poles as shown in Figure 1.

It is for this purpose (to produce a flux equal to $\varnothing_1 + \varnothing_2$) that commutating poles are used on generators. By using commutating poles, sparkless commutation is obtained at all loads (from no load to full load) without shifting the brushes. You have already seen where both armature reaction and the e.m.f. of self-induction in the coil undergoing commutation are proportional to the armature current. Therefore, if the commutation poles are to produce a flux to compensate for these, this flux must be proportional to the armature current. Therefore, the commutating poles are connected in series with the armature so that their flux will increase with load. They are wound with a few turns of wire sufficiently large to carry the armature current.

SKETCH:

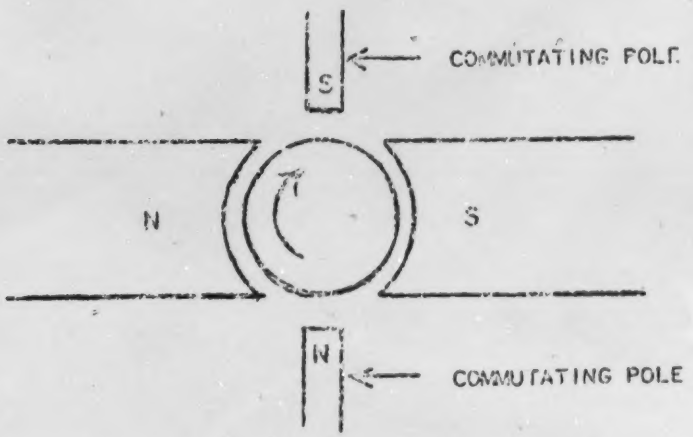


Fig. 1

The air gap between these poles and the armature is large so as to make their flux nearly proportional to the armature current at all loads. For a generator, note the sequence of the poles (Figure 1) for the direction of rotation. The sequence

is Main pole N, Commutating pole S, Main pole S, etc. By doing this the flux produced by the commutating pole will be of the proper direction. Why? By adjusting the number of turns and the current flowing in the commutating field, the flux will be of the proper strength. With this flux the proper direction and strength, the current flowing in the coils undergoing commutation will be zero at the proper instant, and sparkless commutation will be obtained at all loads (from no load to full load) without shifting the brushes.

QUESTIONS:

1. What are commutating poles?

2. What are commutating poles used for?

3. (a) What two things do commutating poles compensate for?
   (b) How do commutating poles compensate? In other words, explain in detail how by the use of commutating poles it is possible to obtain sparkless commutation without shifting the brushes for each load.

4. Why are the commutating poles connected in series with the armature?

5. (a) In a generator what is the sequence of the polarities of the main poles and the commutating poles?
   (b) If the commutating field was reversed what would be the effect?
   (c) Would the sparking be more or less if there were no commutating poles at all? Explain.

6. Why must you, as an electrician, be very careful to set the brushes at the proper position?

REFERENCES:

American Electricians' Handbook

Swoope's Lessons in Practical Electricity

Electricity, Charles A. Rinde

DIRECT CURRENT GENERATORS
ELECTROMOTIVE FORCE OF SELF-INDUCTION

PURPOSE:

To find what effect the electromotive force of self-induction has on communtation.

INFORMATION:

To better understand how self-induction effects commutation, let us recall the elementary Principles of Commutation.

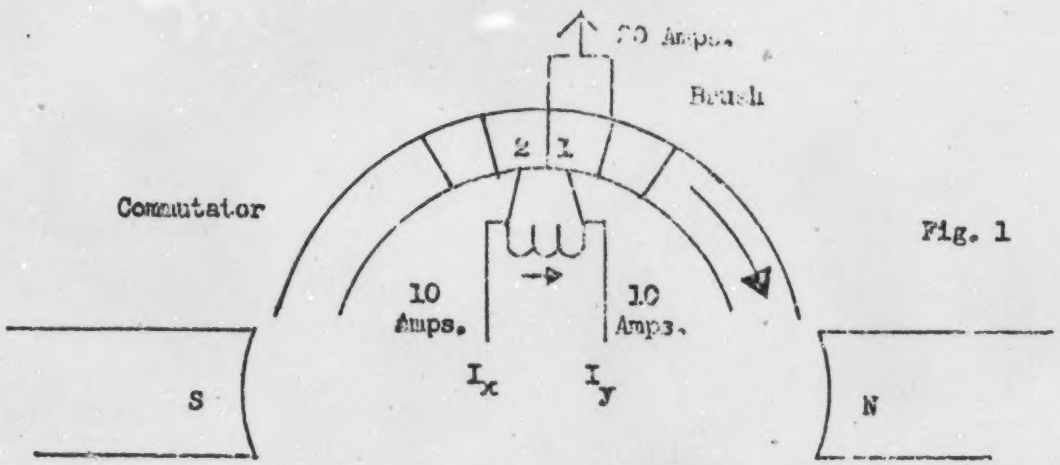


Fig. 1

Figure 1 shows the commutator revolving in a clockwise direction. At the instant shown, commutator bar #1 is directly under the brush. Let us assume that the current in each of the two paths in the armature is 10 amperes. To simplify the explanation a narrow brush is shown (on commercial dynamos the brush covers at least two or three bars). Also, only one of the coils undergoing commutation is shown. The current I_x passes through the armature coil connected across bar #1 and bar #2 in the direction indicated by the arrow, joins the current I_y at bar #1, and the combined current (10 + 10 = 20 amperes) flows from commutator bar #1 to the brush.

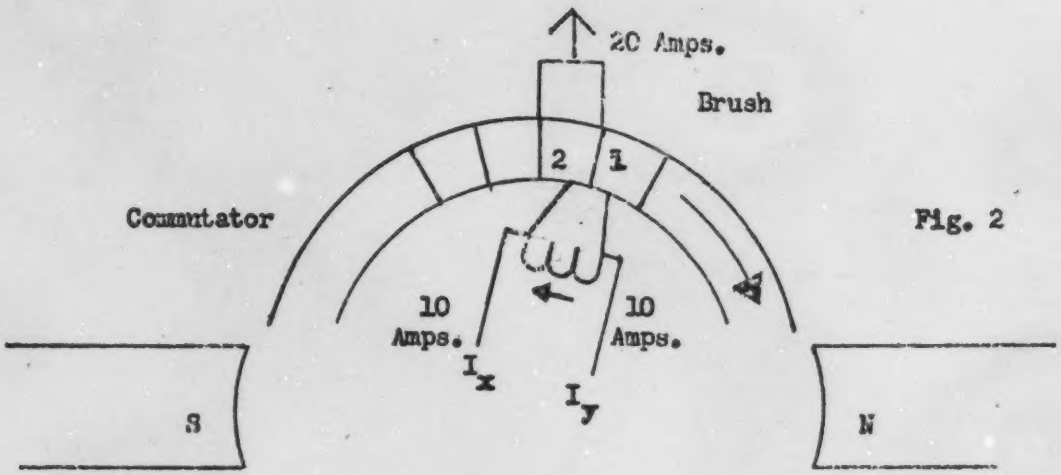


Fig. 2

In Figure 2, the commutator has rotated slightly in a clockwise direction so that bar #2 is now directly beneath the brush. At this instant the current Iy now passes through the coil connected across bar #1 and bar #2 in the direction indicated by the arrow joins the current I_x at bar #2, and the combined current (10 + 10 = 20 amperes) flows from commutator bar #2 to the brush. It should be noted that the current is now flowing in the opposite direction in this armature coil. In other words, in the short period of time (period of commutation) it took for bar #2 to rotate from the position shown in Figure 1 to the position shown in Figure 2 the following things happened to the current in the coil undergoing commutation.

(1) The current reversed in that coil

(2) During the short time interval required for a segment to pass under the brush, the current changed in magnitude from its full positive value (10 amperes) to an equal negative value (10 amperes), as shown in the graph below.

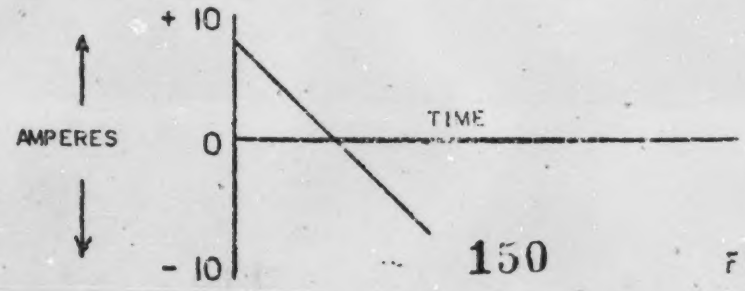


Fig. 3

Since the armature coils are embedded in iron they possess inductance. You found that when the current in a coil changes in strength, an e.m.f. is induced in that coil.

Since the current, in a coil undergoing commutation, changes from its full positive value to an equal negative value (or vice versa) in a very short interval of time, the rate of change of the current is great. Hence, an e.m.f. is induced in the coil.

According to Lenz's law this induced e.m.f. tends to prevent the current reversing in the coil undergoing commutation, and tends to prevent the current becoming zero when the coil is in the neutral plane (Figure 3 of Inf. Lesson 13). Therefore, it is evident that even though the brushes are set on the load neutral, as shown in Figure 3 of Inf. Lesson 13, and hence the coils undergoing commutation are cutting no magnetic lines of force produced by the field poles, nevertheless, due to self-induction an e.m.f. is induced in them.

Again, referring to Figure 1 and Figure 2, to have sparkless commutation the current flowing from bar #1 into the brush must be zero when the brush breaks contact with bar #1. To have this current zero it is necessary that an e.m.f. be induced in the coil which will be excatly equal and opposite to the e.m.f. due to self-induction. One way to accomplish this is to set the brushes ahead of the load neutral shown in Figure 3 of Information Lesson 13. By doing so, the coil undergoing commutation will cut flux in the next pole. This e.m.f. will be opposite in direction to the e.m.f. of self-induction. If the brush is moved forward the proper amount, the e.m.f. induced by this pole will exactly neutralize that produced by self-induction.

From the above it is plainly seen that advancing the brushes to the load neutral plane (Figure 3 of Exp. Lesson 18), so that the coils undergoing commutation will not cut any flux, is not sufficient. The brushes must be further advanced so as to cut flux which will produce sufficient e.m.f. to counteract the e.m.f. of self-induction.

Since the e.m.f. of self-induction not only depends upon the inductance of the coil, but also upon the rate of change of the current, the e.m.f. of self-induction will increase with an increase in load. The time allowed for a coil to undergo commutation is the same at no load as at full load. Therefore, if different amounts of current (for different loads) are to be changed from their full positive values to equal negative values, in equal lengths of time, the rate of change of current must be greater as the load is increased, and hence, the e.m.f. of self-induction will be greater as the load increases. This means that the brushes will have to be farther advanced as the load is increased.

SUMMARY:

As load is applied to a machine (provided with no compensation as later explained) the brushes must be advanced to compensate (a) for armature reaction; (b) the self-induction of the coil undergoing commutation. As both armature reaction and the e.m.f. of self-induction increase with load, the brushes will have to be farther advanced as the load on the machine is increased. The e.m.f. induced in the coil undergoing commutation, due to the shifting of the neutral plane (caused by armature reaction) is comparatively small, as is the e.m.f. due to self-induction. This may range from a few tenths of a volt to possibly five volts. But it must be remembered that they are induced in a circuit of very low resistance. Since the resistance of one coil is extremely low, most of the circuit resistance is at the brush contact.

Since copper brushes have a very low contact resistance, carbon brushes, whose contact resistance is much higher, are used on most machines because they limit the short circuit currents and thereby reduce the destructive action of sparking. (However, the apprentice should bear in mind that this will only partly cut down the sparking). Also the mechanical wear of the commutator is less with carbon brushes than with copper brushes. Inasmuch as there are several different grades of carbon brushes, an electrician must be exceedingly careful when replacing a brush to use the brush designed for the machine. Failure of electricians to observe this precaution has resulted in costly repairs to many a machine. Excessive sparking at the brushes rapidly deteriorates the commutator. (For further details on brushes, see Pgs. 35-40 of "The Brush Phase of Motor Maintenance" by Ohio Carbon Company, Cleveland, Ohio).

QUESTIONS:

1. Give two reasons why the brushes have to be advanced as load is applied.

2. Is the current in the armature alternating or direct?

3. Do the coils on the armature possess self-inductance? If so, why?

4. (a) With the brushes set on the load neutral (Fig. 3, Inf. Lesson 13), the e.m.f. in the coildue to the pole flux is zero. Why?

   (b) Why do the brushes spark in this position? Explain.

   (c) How would you reduce this sparking?

QUESTIONS - Continued

5. For a generator should the brushes be moved in the direction of rotation or the opposite direction as load is applied? Why?

6. What would be the effect upon the commutation, if the brushes were:

   a) advanced too far?
   b) not enough?

7. The voltage induced in the coils (undergoing commutation) due to armature reaction and self-induction are relatively small. Why then, are they so objectionable? Explain in detail.

8. Why are carbon brushes used almost exclusively?

9. Why must you, as an electrician, always be careful to install a brush of the same grade when replacing worn brushes?

10. (a) What is the effect of arcing upon a commutator?

    (b) Upon its appearance, why should it be eliminated as soon as possible?

    (c) Why should you never use emery paper when fitting brushes or sanding a commutator?

REFERENCES:

American Electricians' Handbook, Croft

Swoope's Lessons in Practical Electricity, E. Hausmann

Electricity, Charles A. Rinde

Commercial Generators

DIRECT CURRENT GENERATORS
COMMUTATING POLES (INTERPOLES)

PURPOSE:

To find what effect armature reaction has on commutation.

INFORMATION:

The commercial direct current generator has several coils on its armature and has as many commutator bars (segments) as there are coils. You discovered in Experiment 18 that the alternating current generated within the coils is changed to direct current by a commutator. In that experiment you found that the brushes were so placed that when the coil was perpendicular to the magnetic field (or, in other words, when it was in the so-called neutral plane) the two commutators segments (and hence the coil connected across them) were short circuited by the brushes passing over the cuts in the ring. (See Fig. 3 of Experiment 18). With the coil in the so-called neutral plane (which is a plane perpendicular to the flux) it is generating no voltage. Why? In that experiment the neutral plane (which is a plane perpendicular to the flux) coincided with the geometrical neutral of the system.

In a commercial generator, at all times, at least two of the coils are undergoing commutation (reversing the current in those coils). Just as in the model generator, the coils undergoing commutation are short circuited by the brushes. Hence, the net e.m.f. induced in coils must be zero, because, even with a small e.m.f., a large current would flow in the coils due to their very low resistance. These short circuit currents would cause severe sparking at the brushes, as will be shown a little later.

In Experiment 18 the brushes were so set that the coil undergoing commutation was short circuited when it was in the geometrical neutral plane (mdi-way between the two poles). However, if a load is applied to a machine with the brushes set in this position (assuming the machine is not provided with compensation as later explained) it will be found to spark badly as the load is applied. This sparking is due to two things: (1) armature reaction which will be explained in this lesson; (2) electromotive force of self-induction of the coils undergoing commutation, which will be explained in the following lesson.

ARMATURE REACTION

You have found that any conductor carrying current will set up a magnetic field. Hence, in a generator delivering current, the armature conductors set up a magnetic field due to the current flowing in the armature. This flux reacts with the flux produced by the field coils causing the field to become distorted. This reaction of the two fields is known as Armature Reaction. Fig. 1 shows the flux produced by the field winding of a generator;

Fig. 2 shows the flux produced by the current flowing in the armature conductors; while Fig. 3 shows the resultant field due to the reaction of the flux produced by the current flowing in the armature and the flux produced by the field winding.

Fig. 1 shows the magnetic flux passing from the field poles through an armature in which there is no current flowing. This is the condition you have at no load. The neutral plane coincides with the geometrical neutral of the system. This is the neutral plane at no load.

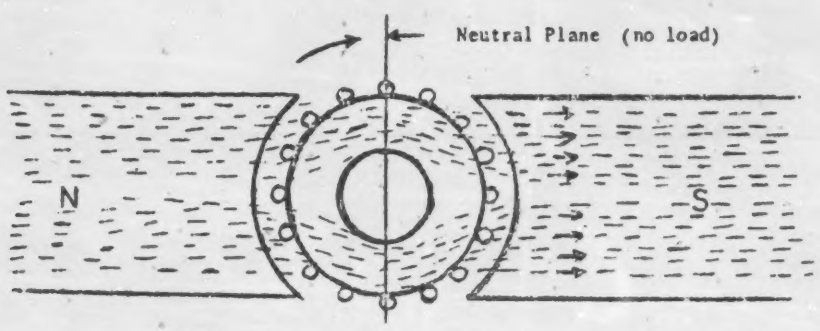


Fig. 1 - Current in Field only

Figure 2 shows how the magnetic circuit of a generator would look if it were possible to have current flowing in the armature but no current in the field coils. You have found that when current flows through a conductor a magnetic field is set up around the conductor. (The lines of magnetic flux form concentric circles about the conductor). You found that, when current was sent through a coil, the lines of force around each individual conductor combined to form a field within and around the coil similar to the field about a bar magnet. Similarly, in an armature carrying current, the lines of force around each individual coil combine to form a field similar to that of a bar magnet, as shown in Figure 2.

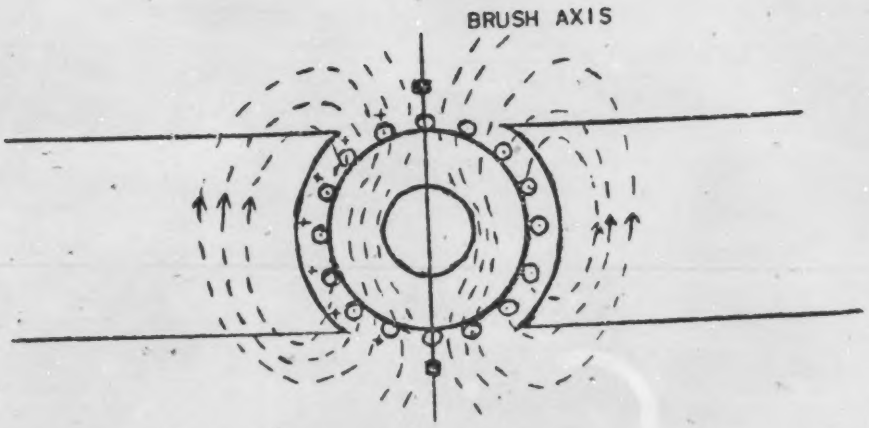


Fig. 2 - Current in Armature only

Fig. 3 shows what happens when there is current both in the armature and the field. This is the condition you have in a generator when under load. The magnetic flux of the field and the magnetic flux produced by the armature coils carrying current react and produce the resultant field shown in Figure 3.

A study of this field shows that two things occur: (1) the field is distorted and the neutral plane (a plane perpendicular to the flux) is shifted in the direction the armature is rotating: (2) the field is weakened at the pole tips A and A_1, and strengthened at the pole tips B and B_1.

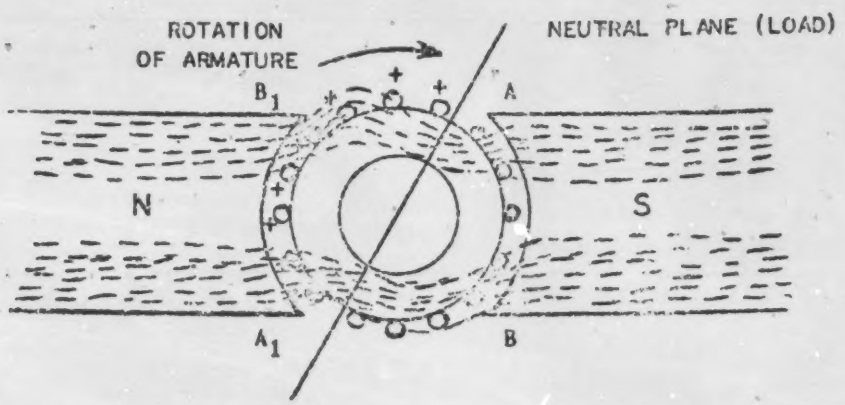


Fig. 3 - Current in Both Armature and Field

As more current flows through the armature, the stronger becomes the armature flux and the greater the reaction. As a result the neutral plane is still further shifted to the right.

A study of Figure 1 and 3 reveals the following facts: (1) with no load on the generator the neutral plane of the flux is mid-way between the poles as shown in Figure 1: (2) when load is supplied to the machine the field becomes distorted and the neutral plane of the flux is shifted to a new position as shown in Figure 3. (The neutral plane of the flux will be different for each value of armature current).

This shifting of the neutral plane of the flux will cause sparking if the brushes are not shifted as load is applied. The reason for this is: with no load on the generator the coil is not cutting any flux when it is in the neutral plane, shown in Figure 1. But when load is applied, it will be cutting flux when in that plane because there now exists an appreciable amount of flux (due to armature reaction) in the neutral zone. This will induce an e.m.f. in the coil. Hence, if the brushes are left on the no load neutral plane, sparking will result. The coil will not be cutting any flux when in the load neutral plane shown in Figure 3. Therefore, if the brushes are to short circuit the coil when it is cutting no flux, the brushes will have to be advanced as load is applied.

With the brushes placed on the load neutral, the coil undergoing commutation will not be cutting any flux. However, sparkless commutation will not be obtained even if the brushes are advanced to the load neutral. The reason for this is that although the e.m.f. induced in the coil (undergoing commutation) by pole flux is zero, there is an e.m.f. in this coil due to its own self-induction which will be explained in Inf. Lesson 14. To compensate for this e.m.f. of self-induction the brushes must be still further advanced. Advancing the brushes to the load neutral plane (Figure 3) only compensates for armature reaction.

QUESTIONS:

1. What is your idea of armature reaction?

2. What does it do to the field?

3. What does it do to the neutral plane of the flux?

4. What is your understanding of the term "neutral plane of the flux"?

5. (a) When a conductor passes through the neutral plane of the flux, is any flux cut?

   (b) Is any e.m.f. induced in the conductor by the field flux? Explain.

6. With brushes set on the geometrical neutral, Figure 1, (mid-way between the poles) explain in detail why armature reaction causes sparking at the brushes as load is applied to the machine. (Assume the machine does not have commutating poles or other means of compensation).

REFERENCES:

American Electricians' Handbook, Croft

Swoope's Lessons in Practical Electricity

Electricity, Charles A. Rinde

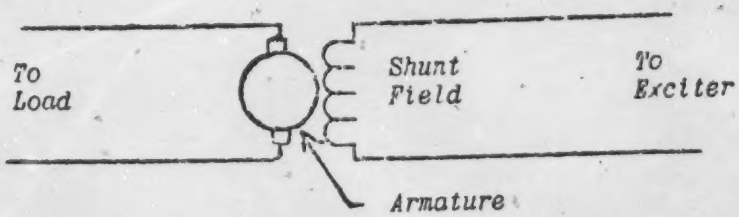
DIRECT CURRENT GENERATORS

TYPES OF EXCITATION:

(a) Separately-Excited Generators

A separately-excited generator is one in which the current for magnetizing the field magnets is supplied from a separate source such as batteries, a separate D.C. generator called an exciter, etc. The commercial A.C. generator is an example of a separately-excited generator. Figure 1 shows the connections for a separately-excited D.C. generator.

Fig. 1



(b) Self-Excited Generators

Although D.C. generators may be separately-excited, the generator itself usually supplies the current for magnetizing the field. Such a machine is said to be self-excited.

In previous experiments, you found that when the current in an electromagnet is turned off, the magnetism does not all disappear (residual magnetism). Since the field coils of a generator are electromagnets, a little residual magnetism is left in them when the machine is shut down. When the armature is rotated, its conductors cut this residual flux, and a small e.m.f. is induced in the armature. This will cause a small current to flow through the field winding which will set up a small flux and if this flux is in the same direction as the residual flux, the field will be strengthened. This will increase the voltage induced in the armature which in turn will cause more current to flow through the field. More flux will be produced by this, which in turn will again increase

the e.m.f. of the armature. This continues until the machine builds up its proper voltage. This building up is a very rapid process (10 or 20 seconds).

TYPES OF FIELD WINDINGS FOR D.C. GENERATORS

(a) Series Generators

In the series generator the field is connected in series with the armature. It is wound with a few turns of heavy wire, thus having a low resistance. This wire must have a dufficiently large cross-section to carry the rated current to the generator. These generators are used, in most cases, for constant current work. In the past, series generators have been used in series arc lighting. However, series circuits in the United States are now used only for street lighting, and even here constant current transformers, fed from a constant potential system, are used instead of series generators. When direct current is needed, constant current transformers and mercury arc rectifiers are used. However, in Europe, power is often transmitted by direct current at high potential (as high as 50,000 volts). This high voltage is obtained by connecting several series generators in series.

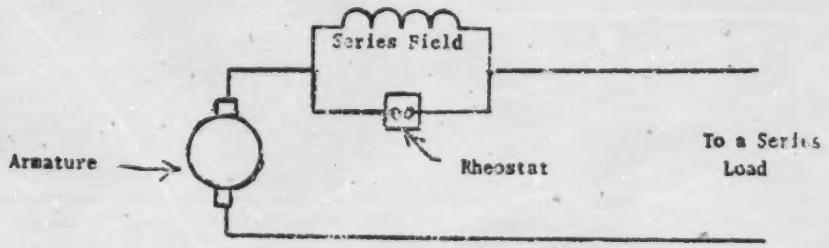


Fig. 2

Series generators are often used as boosters on direct current feeders to prevent excessive line drops.

As the load (current) on a series generator increases, the voltage rises, because the larger field current produces a stronger magnetic field. In practice, the series generator is required to produce a constant current irrespective of the resistance of the external circuit. One practical method of accomplishing this is to connect an adjustable rheostat in parallel with the series

field. (Figure 2). The arm of this rheostat is automatically moved by a solenoid actuated by the line current.

(b) Shunt Generators

In the shunt generator the field is connected in parallel or is in "shunt" with the armature. It is wound with a great many turns of small wire. The resistance of the field is relatively large as compared to the armature resistance. Hence, the field current is small. The voltage of the machine is regulated by a rheostat (called a field rheostat) inserted in the shunt field. (Figure 3).

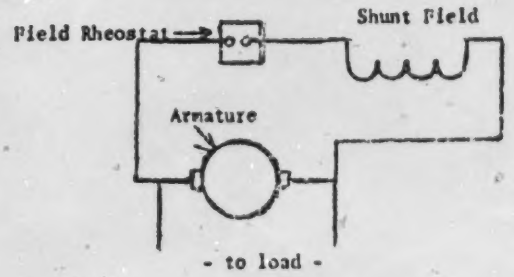


Fig. 3

The resistance of a dynamo armature is relatively small and varies with the capacity of the machine. For example, machines of 1 Kw. - 115 volts may have an armature resistance of approximately 1 ohm, while the armature resistance of a 25 Kw. - 115 volt machine may be about 0.025 of an ohm. (The armature resistance decreases with an increase in size). Likewise the field resistance varies with the capacity of the machine.

Example: the shunt field resistance of a 1 Kw. - 115 volt machine may be approximately 250 ohms while it is only approximately 20 ohms for the 25 Kw. - 115 volt machine.

(c) Compound Generators

The voltage of a shunt generator drops off as load is applied. There are three reasons for this. (1) The terminal voltage equals the induced voltage minus the IR drop in the armature. As more current is drawn from the machine the greater will be the IR drop in the armature. Why? (2) Armature reaction (the magnetism set up by the current in the armature coils

interferes with the field magnetism), weakens the field and hence reduces the induced voltage. (3) The decrease in terminal voltage due to (1) and (2) results in a decrease in field current. This in turn, of course, results in a smaller induced voltage.

In a series generator, all the armature current passes through the field. Therefore, as the load (current) increases the voltage rises because the large field current produces a stronger magnetic field. Therefore, it stands to reason that if a machine has both a shunt field and a series field (such a machine is called a compound generator) it will possess the characteristics of both series and shunt generators.

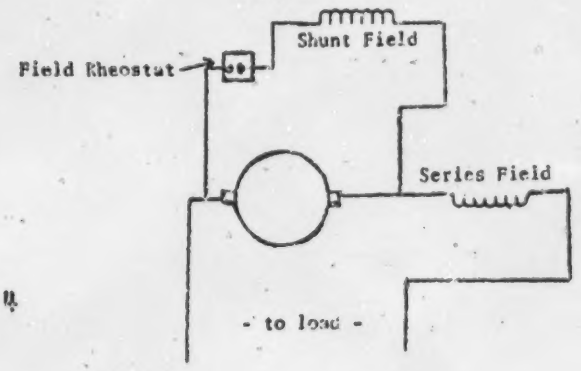


Fig. 4

In the compound generator (Figure 4) the series field is so connected as to aid the shunt field. By properly adjusting the series field it is possible to have:

(a) The voltage at full load the same as at no load (this is called a flat-compounded generator).

(b) The voltage at full load greater than the no load voltage, (this is called an overcompounded generator).

(c) The voltage at full load less than the no-load voltage (this is called an under-compounded generator).

Generators are seldom under-compounded. Over-compounded generators are used where the load is located some distance from the generator.

In a compound generator, the shunt field may be connected across the armature as shown in Figure 4. Or, it may be connected across the terminals of the generator as shown in Figure 5.

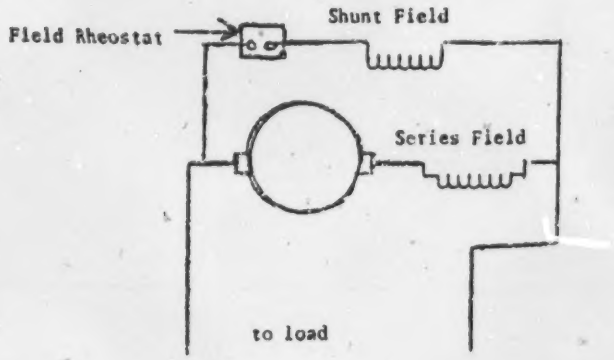


Fig. 5

If the shunt field is connected across the armature as shown in Figure 4, it is called a SHORT-SHUNT COMPOUND GENERATOR. Compound generators are usually connected Short-Shunt because the shunt field current tends to remain more nearly constant as the load on the machine is varied. Why?

If the shunt field is connected across the terminals of the generator as shown in Figure 5, it is called a LONG-SHUNT COMPOUND GENERATOR. You will find that compound motors are usually connected Long-Shunt.

QUESTIONS:

1. What is a self-excited generator? Draw a sketch.
2. What is a separately-excited generator? Draw a sketch.
3. Does a separately-excited generator depend on residual magnetism for building up?
4. (a) Are series generators now used in the U.S. for lighting purposes?
   (b) Are they used to any great extent?

QUESTIONS - Continued

5. Why should a generator be driven at as nearly constant rated speed as possible?

6. An electrician, in testing a series generator, used too high a resistance for the load. He ran the generator at rated speed and had the proper connections, but the generator failed to build up. He reduced the resistance of the load and the generator voltage built up.

   (a) How do you account for this?
   (b) If the generator had been a shunt or a compound machine, would he have encountered this difficulty?
   (c) Would he have wasted this valuable time, if he had known the theory of series generators?

7. (a) Does decreasing the resistance of the field rheostat of a shunt or compound generator raise or lower the voltage induced in the armature? Why?
   (b) What effect has increasing the resistance of the field rheostat of a generator upon the induced armature voltage?

8. May a shunt generator be either separately or self-excited?

9. In your own words, explain how a self-excited generator builds up.

10. For any of the following reasons a self-excited generator may fail to build up:

    (a) Loss of residual magnetism.
    (b) Field resistance too high.
    (c) Field circuit open.
    (d) Machine running below its rated speed.
    (e) Improper field connection for the direction or rotation.
    (f) Brushes not properly placed.

    For each item mentioned above, explain why that particular thing would cause a self-excited generator not to build up.

11. If a self-excited D.C. generator fails to build up, explain in detail how you would go about to find and remedy the trouble.

12. The terminal voltage of a D.C. generator is found by using the following formula:

$$Vt = Ea - (Ia \times Ra)$$

Where: - Vt is the terminal voltage
Ea is the voltage induced in the armature
Ia is the armature current
Ra is the resistance of the armature

QUESTIONS - Continued

12. (a) Write the formula for finding the terminal voltage of a battery.

    (b) If the armature resistance of a certain shunt generator is 0.03 ohm and the armature current is 218 amperes, what is the induced voltage when the line voltmeter reads 115 volts?

13. Explain why the terminal voltage of a shunt generator drops off as load is applied.

14. What is the essential difference between a shunt generator and a compound generator?

15. What is the difference between
    (a) flat-compounded
    (b) under-compounded
    (c) over-compounded generator

16. Why is it necessary to reverse the field-coil terminals when the direction of rotation of a self-excited tenerator is reversed?

17. (a) What is indicated if the voltage of a compound machine drops off badly as the machine is loaded? Why?

    (b) Explain how you would remedy the condition.

18. (a) Explain in detail how it is possible, by using a compound generator with the proper degree of compounding, to hold the voltage substantially constant (from no load to full load) at a load located 3,000 feet from the generator.

    (b) Suppose the load was located 7,000 feet from the generator (degree of compounding left unchanged)- would the voltage at the load still remain constant?

    (c) Is the machine referred to in this question flat-compounded, over-compounded, or under-compounded? Prove your answer.

19. A shunt generator is delivering 21 amperes to the external circuit. The resistance of the field is 80 ohms and the terminal voltage is 115 volts.
    (a) What current does the field take?
    (b) What current flows out of the armature? Show all calculations.

QUESTIONS - Continued

20. In compound wound generators compare the size wire and the number of turns of the series field to the size wire and number of turns on the shunt field.

21. Referring to Figure 6, answer the following:
(a) What do A_1 and A_2 designate?
(b) S_1 and S_2?
(c) F_2?

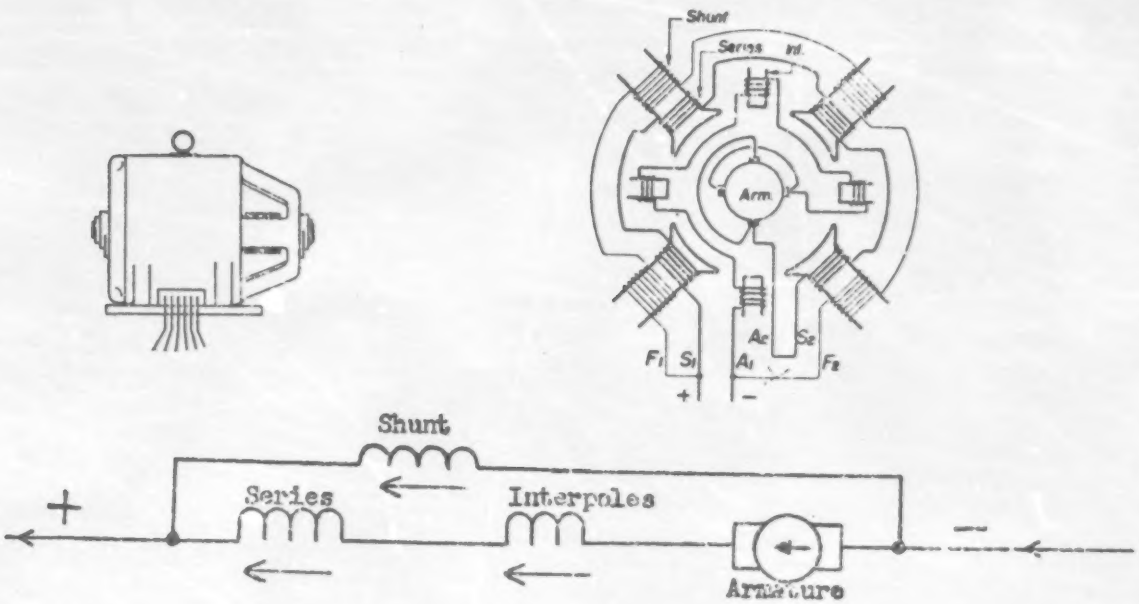


Figure # 6. A four-pole compound-interpole generator.

22. Make a wiring diagram of each direct current generator in your department.

REFERENCES:

Basic Electricity, Marcus
Swoope's Lessons in Practical Electricity, E. Hausman
American Electricians' Handbook, Croft 9th Edition

Commercial Generators

DIRECT CURRENT GENERATORS
LOSSES - EFFICIENCY

LOSSES:

Not all of the mechanical energy supplied to a generator is converted into electrical energy. A certain portion of energy delivered to a generator is converted into heat and is therefore wasted. This represents a loss and it has a further objection in that it heats the generator and limits its output. If this loss becomes excessive, the resulting temperature rise will carbonize the insulation and soon the machine will break down. The losses in a generator (or motor because you will find later that a motor and a generator are similar) are divided into three groups as follows:

(1) Copper Losses:
- (a) in the armature
- (b) in the fields
- (c) brush contact resistance loss

(2) Iron Losses:
- (a) eddy-current losses in the armature core, the field-pole faces, and other metal
- (b) hystersis losses in the armature core and the field-pole faces

(3) Mechanical Losses:
- (a) bearing friction
- (b) brush friction (brushes rubbing on the commutator)
- (c) windage (friction of armature against surrounding air)

(1) Copper Losses

The armature has a certain resistance. Hence like any other resistance when current flows through it there will be an I^2R loss. Similarly, there is an I^2R loss in the series and shunt fields.

(2) Iron Losses

Eddy currents - Since the armature iron rotates in the same magnetic field as the copper conductor, currents are set up in the iron core. (The rule, that electric currents are set up

when a conductor cuts lines of force, applies for iron just as it does for copper.) Hence, this current circulating in the iron represents a loss.

Hystersis losses - You discovered in previous experiments that alternating current is produced within a direct current generator. Hence, there is a hystersis loss in the armature, as in any alternating current machinery.

The iron losses in the pole faces are due to the movement of the armature teeth past the faces of the poles.

(3) Mechanical Losses

These are practically constant at all loads, if speed is constant.

EFFICIENCY:

From the above it is evident that a generator does not deliver as much useful energy as is required to run it. By efficiency is meant the relation existing between useful work done (output) to the total energy required to run it (input). In other words, the ratio of efficiency of any device is equal to output divided by input. If it were possible to have a perfect generator, it would convert all the mechanical energy supplied it into useful electrical energy. But as already pointed out part of the energy supplied is wasted.

$$\text{Thus, Percent Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100$$

This formula may be rewritten to read,

$$\text{Percent Efficiency} = \frac{\text{Output}}{\text{Output Losses}} \times 100$$

In using the above formula, care must be exercised to use the same unit for power output and power input. Electrical units (watt, kilowatt) rather than mechanical units (foot-pound per second, horsepower) are usually used in determining efficiency.

QUESTIONS:

1. What is your idea of the term "efficiency"?

2. (a) Why are armature cores laminated?
   (b) Does laminating the iron reduce the hystersis loss? Explain.

QUESTIONS - Continued

3. (a) What becomes of the energy lost in a generator?
   (b) Is it useful?
   (c) What effect has it on the generator?

4. Name all the losses in a generator.

5. What determines the rating of a generator? (See Jackson & Black - Page 220).

6. Hos iw the hystersis loss reduced in an armature?

7. Do the following appliances, etc., ever attain 100% efficiency? Explain your answer on each case.
   (a) A generator
   (b) A motor
   (c) A transformer
   (d) A lamp
   (e) An electric toaster
   (f) A gasoline engine
   (g) A turbine

8. A 10 KW shunt generator has the following losses at full load:

   Armature loss 515 watts
   Shunt field loss 326 watts
   Iron and mechanical losses 652 watts

   Calculate the full load efficiency.

9. A certain shunt generator is delivering 18.5 amperes (line current) at 230 volts. The current drawn by the field is 0.615 amp. The hot resistance of the armature is 0.5 ohm. If the iron and mechanical losses total 360.7 watts, find the efficiency of the generator at that load.

10. If the full-load efficiency of a 100 KW shunt generator is 92%, what horsepower will be required to drive it?

11. How large an engine will be required to drive a 2 KW compound generator whose full-load efficiency is 74%?

12. It requires approximately 55 KW to drive a 50 KW D.C. generator when fully loaded. What is the full-load efficiency of the generator?

QUESTIONS - Continued

13. In commercial D.C. generators, the armature core is laminated while the field poles may or may not be laminated. Why is the armature core always laminated while the field poles of some small D.C. machines are solid steel?

REFERENCES:

Swoope's Lessons in Practical Electricity - E. Hausmann

American Electricians' Handbook

THE HOMOPOLAR GENERATORS

PURPOSE:

To study the principle and operation of the acyclic or homopolar generator.

THEORY OF OPERATION:

If the metal strip A is moved so as to cut lines of force, and E.M.F. will be established between the brushes or sides of the strip (Figure 1) and a continuous current sent around the external circuit connecting them.

THE RADIAL TYPE:

This type shown in Figure 2, consists of a metallic disk, rotating between poles which are excited by field coils wound concentric with the shaft. The brushes are placed at A and B, and holes are cast in yoke to allow access to the brushes. In Figure 3, there are two disks mounted on the same shaft so that they are electrically connected at the hub, and the total E.M.F. is twice that of one disk.

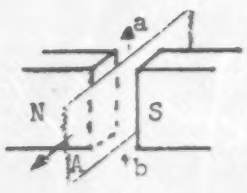


Fig. 1

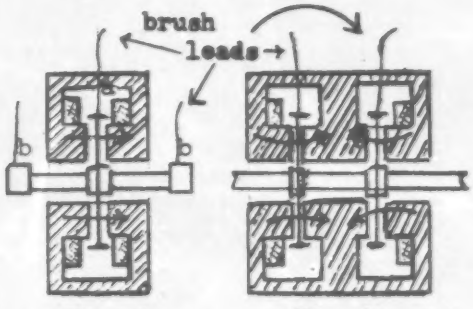


Fig. 2

Fig. 3

INFORMATION:

This type of machine is used where a constant voltage is essential. One of the more important applications is in the detection and location of flaws in car rails. The generator is usually designed for low voltage high current output. Producing a voltage of one and one-half to two volts and having a current output of 2000 to 3000 amperes.

INFORMATION - Continued

In the process of checking car rails the flaw is detected by apparatus suspended from a test car and while traveling at twelve to fifteen miles per hour. At the instand a flaw is indicated a paint gun shoots the rail at the approximate location. The car is stopped and the operators apply 2000 to 3000 amperes through the rail longitudinally along the place indicated. A millivoltmeter is then used to find the exact location of the flaw by measuring the voltage drop along the rail. The greatest voltage drop is at the flaw. The larger the flaw the greater the voltage drop.

Another application is in the welding of steel pipe. In one steel mill a Homopolar generator which produces 7½ volts and 150,000 amperes is in use.

There are other applications of this type of generator but they are few because of the expense involved in the construction.

QUESTIONS:

1. How many poles has the Homopolar generator?
2. Homopolar generators are not designed for high voltages. What do you think is the reason?
3. Commutators are not used on these machines. Why?
4. How would you reserve the polarity of the terminal voltage on this type of generator?

REFERENCES:

American Electrical Engineers Handbook

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 19
Page 1 of 5

Commercial Generators

THE THIRD-BRUSH (AUTOMOBILE) GENERATOR

PURPOSE:

To study the construction and operation of an automobile generator.

MATERIALS USED:

Third-brush generator, variable speed motor, ammeter, voltmeter, belt, pulley, 6-volt storage battery.

PROCEDURE:

(1) Remove the end shield from the commutator end and carefully study the construction and internal connections of the generator. Make a wiring diagram. (See Question 1).

(2) Replace the end shield. Belt the generator to a variable speed motor. Connect a 6 volt-storage battery so that it will be charged by the generator. Include a voltmeter and an ammeter in the circuit. (Have your connections checked by your instructor).

Run the generator at a speed corresponding to about 5 miles per hour (engine speed). Record the voltmeter and ammeter readings when the generator is running at the following speeds, which are only approximate:

10 miles per hour (500 R.P.M.)
25 miles per hour (1250 R.P.M.)
30 miles per hour (1500 R.P.M.)
40 miles per hour (2000 R.P.M.)
50 miles per hour (2500 R.P.M.)

(3) Move the third brush about 10 degrees in the direction the commutator is rotating. Run the generator and note the effect, if any, upon the charging rate. Repeat with the third brush shifted still further in the direction of rotation. Again note the effect, if any, upon the charging rate. Repeat until the brush has been moved the maximum permissible distance in the direction of the rotation.

PROCEDURE (Continued)

(4) Repeat Part (3) moving the third brush in a direction opposite to that which the commutator is rotating. Note the effect, if any, upon the charging rate.

(5) Record the no-load voltage of the generator.

(6) Study the construction and operation of the cutout.

QUESTIONS:

1. Make a schematic wiring diagram of the automobile generator assigned you.

2. (a) Are automobile generators run at a constant speed?
   (b) Why couldn't an ordinary shunt generator be used on an automobile?

3. What were the charging rates at the various speeds of the generator?

4. (a) What effect, if any, did moving the third brush in the direction of armature rotation (commutator end) have upon the charging rate?
   (b) What was the effect, if any, when the third brush was moved opposite to the direction of rotation?

5. What new fact have you discovered in this experiment?

EXPLANATORY NOTES;-

The Third-Brush Generator is used on automobiles to generate current to charge the storage battery, to light the lamps, etc. In the generators studied in previous experiments, you found that the e.m.f. increased as the speed increased. It is evident that these generators could not be used on automobiles because the generator is driven by the automobile engine which sometimes runs fast and sometimes slow. The voltage of the generator must not go above a certain limit, because if it did the filaments of the bulbs would burn out, charging rate for the battery would be too high, etc. Thus we see that the automobile requires a variable-speed generator which will deliver a reasonably constant current to charge the storage battery.

EXPLANATORY NOTES (Continued)

One type of generator that will give this result is the Third-Brush Generator shown in Figure 1. It is a bi-polar generator, It has two main brushes A and A_1 as in the regular generator. (The load is connected across the brushes).

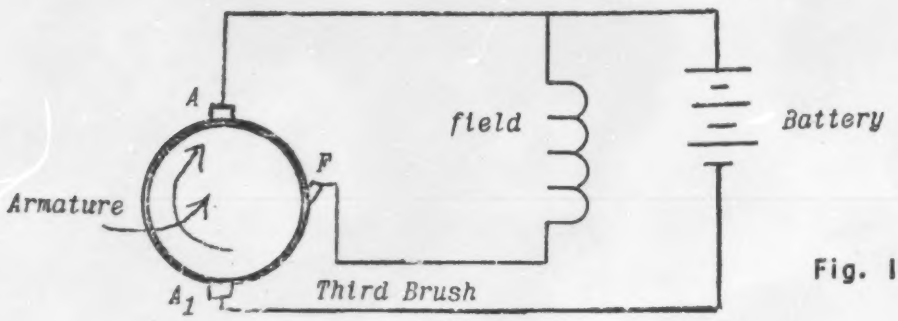


Fig. 1

Between these brushes is placed a third brush "F". The field is connected across this third brush and one of the main brushes as shown in Figure 1. This shows the field connections for a clockwise rotation of the armature facing the commutator end. For a counter-clockwise rotation, the third brush may be placed on the other side of the commutator; or it may be left on the side shown, and the field connected across F and A_1 as shown in Figure 2.

Imagine that the car is running at 20 miles per hour and is delivering the proper current for charging the storage battery. Suppose the operator increases the speed of the car to 40 miles per hour. This increase in speed will tend to increase the e.m.f. and the current flowing in the armature. But you found, that when current flows in the armature of a generator armature reaction occurs. The larger the current, the greater the armature reaction. In that Experiment (See Figure 3) you found that armature reaction shifted the neutral plane of the flux ahead and weakened the flux at the pole tips A and A_1. This means that, as more current tends to flow, the net flux in the zone between A and F (Figure 1) of this experiment is reduced. This weakened field decreases the e.m.f. generated in the coils on the armature between A and F, of Figure 1. Since the field is connected across A and F, the field voltage, and hence the field current, is reduced. This in turn decreases the main field flux. A decrease in the main field flux not only decreases the e.m.f. across A and F, but also between A and A_1. Decreasing the voltage across A and A_1 reduces the current delivered to the storage battery. With proper design this current will be reduced to very nearly the normal value and the current is held reasonably constant over a wide range of speed.

EXPLANATORY NOTES (Continued)

In several of the modern automobile generators the current increases for increases of speed up to 20 to 22 miles per hour. When the speed is raised above this point the current falls off slightly instead of increasing. The maximum value of the current can be regulated by shifting the position of the brush. This generator is an example of where armature reaction is made use of to automatically regulate the strength of the field and hence the current delivered by the generator.

REVERSE CURRENT RELAY

It is evident that some form of a reverse current relay must be used to automatically break the circuit between the generator and the battery when the generator is not running, or when the engine speed is too low, (usually a car speed of less than 10 miles per hour) for the generator to charge the battery. One form of relay is shown in Figure 2. This relay has two separate coils. The potential coil "V" is connected across the circuit, while the coil "I" is in series.

NOTE: THE APPRENTICE MUST REMEMBER THAT THIS RELAY IS NOT USED TO OPEN THE CIRCUIT WHEN THE BATTERY IS FULLY CHARGED. Its only functions are (1) to close the circuit when the generator is delivering enough current to charge the battery; (2) to disconnect the generator from the battery when the speed falls below a certain value (usually a car speed of about 10 miles per hour).

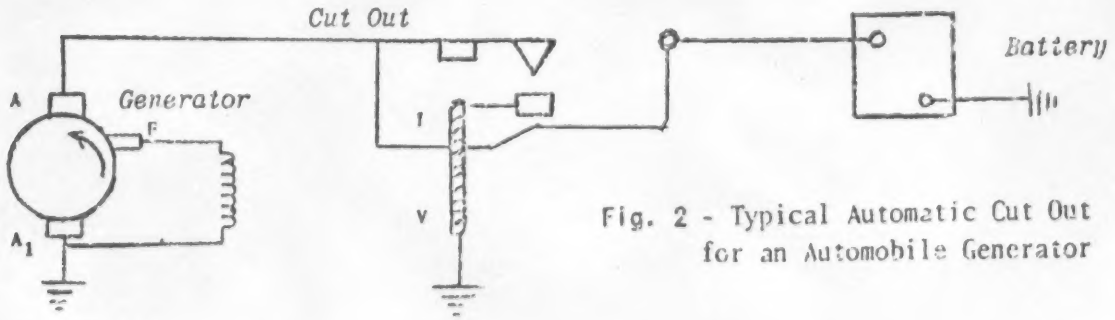


Fig. 2 - Typical Automatic Cut Out for an Automobile Generator

The potential coil "V" of the relay is permanently connected across the generator (See Figure 2). Suppose the engine is started. When it reaches a car speed of about 10 miles per hour, the generator voltage is enough to energize the coil "V" sufficiently to close the relay contacts. When the contacts are closed the current from the generator flows through the series coil "I" of the relay to the battery. The current flows through this coil in the same direction as the current flows through the coil "V". Therefore, it strengthens the

EXPLANATORY NOTES (Continued)

flux produced by the coil "V", and the contacts will remain closed. Suppose the car speed drops to such a value (usually less than 10 miles per hour) that the voltage produced by the generator is less than the terminal voltage of the battery. The current will now flow in the series coil "I" in an opposite direction. This reversed current will set up a flux which will oppose the flux produced by the coil "V". As a result, the flux in the core of the electromagnet will become so weak that its attraction for the armature of the relay will not be enough to overcome the action of the spring on the armature. Therefore, the contacts of the relay will open and the generator will be disconnected from the battery.

QUESTIONS (Continued)

6. (a) How many windings has the cutout (reverse-current relay) on an automobile generator?
   (b) Where is the potential winding connected?
   (c) Explain how the cutout operates.
   (d) What is the cutout used for?
   (e) At what car speeds are cutouts usually adjusted to operate?

7. Is the cutout used for the purpose of opening the circuit, where the charging rate becomes too high?

8. Is the cutout used for the purpose of opening the circuit when the battery becomes fully charged?

9. How does the third-brush generator differ from the common shunt generator in:
   (a) construction
   (b) operating characteristics

10. Explain in detail how it is possible to obtain a reasonably constant current over a wide range of speed with a third-brush generator.

REFERENCES:

Elements of Electricity, Timbie
Electricity, Charles A. Rinde

PRELIMINARY TESTS AND INSPECTION OF GENERATORS

PURPOSE:

To acquaint the student with the preliminary tests and inspections recommended for generators.

EXPLANATION:

You have already studied the variety of generators in use today. An important part of effective operations of generators is the proper testing and inspecting of generators before they are placed into use.

WHEN NOT IN USE (STANDBY)

When a generator is not being used constantly, it should be cared for and in ready condition to be operated. A record should be kept of services and inspections.

1. Lubricate the generator properly, keep record of lubrication and lubrication checks.
2. Keep commutator, slip-rings and machinery clean and free from water, dust, and foreign objects.
3. At set periods of time bring generator up to speed (about every twoweeks) and check bearings, rheostat, circuit breakers, and all auxiliary equipment. Record these operations and results.

WHEN STARTING GENERATOR TO PLACE IN OPERATION

When starting generators for use, certain procedures are usually followed. Listed below are some suggested steps:

1. Examine the bearings, see that there is enough oil and that the oil rings are working.
2. See that the field rheostat is cut into circuit so that the voltage is low as possible.

WHEN STARTING GENERATOR TO PLACE IN OPERATION - Continued

3. Start the Prime Mover (Motor-Turbine, etc.) slowly and let generator come up to speed.

4. Examine oil rings again, see that all is working correctly, listen for any unfamiliar sound.

5. Cut out field resistance (Rheostat) until voltage is a little above bus bar voltage (Line Voltage).

6. If machine is stabilized shunt or compound and equalizer is not part of main switch, close equalizer switch at this point.

QUESTIONS:

1. Why do we keep records of care and maintenance of Generators?

2. Why do we bring up generator speed gradually and with no or little voltage at start?

3. Make a list of the things you would do if you had charge of a group of Generators.

REFERENCES:

Fundamentals of Electricity, Theodore Benjamin

G.E. Generator Care Manual

Westinghouse Generator Care Manual